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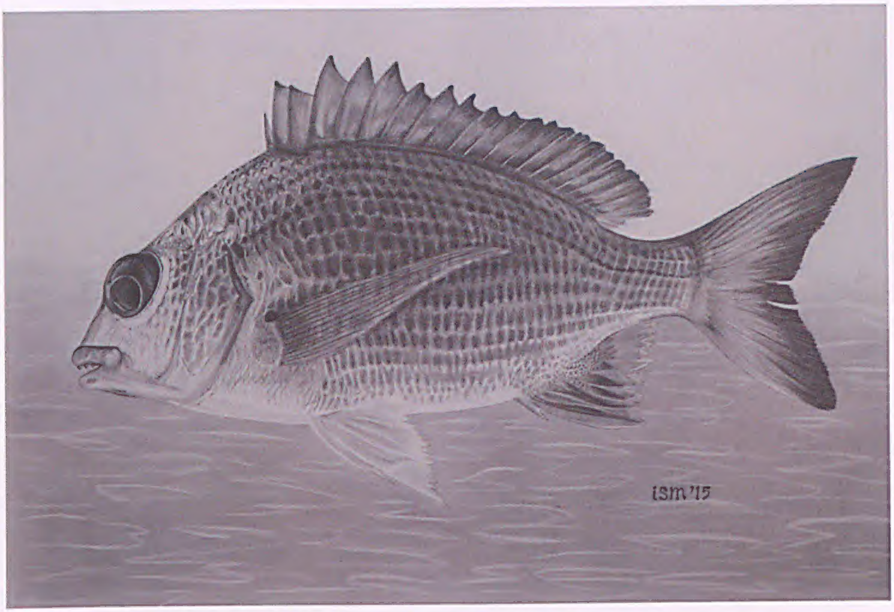

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THE BIOLOGY AND NATURAL HISTORY OF *TRIPOGON LOLIIFORMIS* (POACEAE, CHLORIDOIDEAE), AN AUSTRALIAN RESURRECTION GRASS

SCHARASCHKIN, T. & FABILLO, M.

Tripogon loliiformis is a desiccation-tolerant grass that occurs throughout mainland Australia. There has been recent interest in this species as a model system for understanding desiccation tolerance in a native grass at the structural, molecular and physiological levels. However, not much is known about the biology and natural history of this species, despite its widespread geographic distribution and remarkable capability of withstanding prolonged drying. We provide an overview of the genus by consolidating information from a wide variety of sources. We report a variety of new and interesting observations on the general biology, ecology and desiccation response of *T. loliiformis* and conclude by highlighting areas for future research.

Keywords: Desiccation tolerance, inselberg flora, pigmentation, phenotypic plasticity, leaf anatomy

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INTRODUCTION

The ability of vegetative organs (e.g., leaves) to survive air dryness is rare among angiosperms (Gaff, 1971; Farrant, 2000; Vicre et al., 2004). Plants that can survive extreme drying (~80-95% water loss) and then resume normal function after rehydration are said to be desiccation-tolerant (Tuba et al., 1998; Alpert, 2000). This condition is different from drought tolerance, which is associated with moderate dehydration (~23% water loss) (Tuba et al., 1998; Hoekstra et al., 2001). Given that desiccation-tolerant plants appear to "resurrect from the dead" once rehydrated, they are commonly called "resurrection plants" (Gaff & Latz, 1978).

Whilst some Australian desiccation-tolerant grasses, such as *Sporobolus stapfianus* and *Borya nitida*, have been the focus of detailed study for many decades (e.g., Gaff & Churchill, 1976; Hethzerington et al., 1982; Gaff, 1989; Blomstedt et al., 1998; Le et al., 2007), it is only recently that the desiccation tolerance capability of *Tripogon loliiformis* has been the focus of physiological and molecular investigations. An understanding of the water-use efficiency and desiccation tolerance mechanisms of a native resurrection grass could lead to the improvement of these traits in economically important grasses such as rice, sorghum and wheat (Mundree, pers. comm.). A detailed study of the molecular and physiological changes in *T. loliiformis* during different stages of dehydration and rehydration are under investigation as part of a PhD research project (Karbaschi, pers. comm.).

Tripogon loliiformis is a widespread and morphologically variable desiccation-tolerant grass that occurs across the Australian mainland and the island of New Guinea (FIG. 1). Despite the widespread distribution, its habitat requirements are quite specific and in certain areas, such as Victoria, it is under threat from land development, rock removal and stock grazing (Just & Evans, 2010). The morphological variability observed in this species has led various researchers to suggest that *T. loliiformis* could be multiple species (Gaff & Latz, 1978; Olsen, 1983; Palmer & Weiller, 2005). Within Queensland alone, plants from north-eastern Queensland are considered morphologically different from those of southern Queensland (Palmer & Weiller, 2005). Even though *T. loliiformis* occurs throughout Australia, very few studies have been conducted on this species.

In this paper we present a wide range of observations and insights on the biology, ecology and resurrection behaviour of *T. loliiformis* gained while conducting a phylogenetic study on the genus *Tripogon* (Fabillo, 2015). We review and consolidate information about the genus from disparate sources, including taxonomic, ecological, agronomic and ecophysiological literature. There is an extensive body of literature on the physiology and molecular biology (gene expression and regulation) of desiccation-tolerant plants, which

far exceeds the scope of this paper. We therefore limit the scope of this paper to ecological and biological aspects (particularly morphological and anatomical) associated with desiccation tolerance of *T. loliiformis*. We consider it a worthwhile endeavour to document and publish our observations on the natural history of this species due to the potential interest to the wider scientific community. An additional aim of this paper is to provide a comprehensive overview of this species in its natural habitat for those working on molecular and physiological mechanisms in the laboratory. We highlight numerous gaps in our understanding of the biology of *T. loliiformis* and hope that this will spur further research.

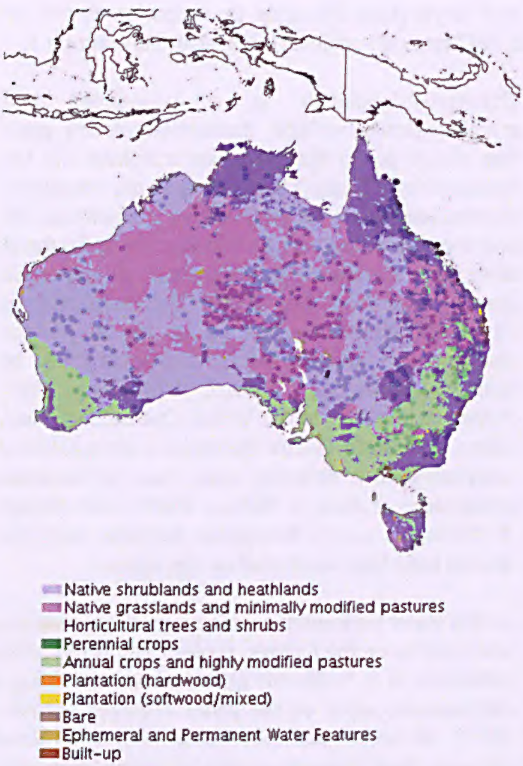


FIG. 1. Geographical distribution of *T. loliiformis*. Dots represent locations from herbarium specimen recorded in Australia's Virtual Herbarium (AVH). Map obtained from AVH (http://avh.ala.org.au/).

OVERVIEW OF THE GENUS

The name *Tripogon* is derived from the Greek words *treis* (three) and *pogon* (beard, referring to tufts of hair), due to the presence of clumps of hairs located at the base of three veins on the lemma of each floret (Watson and Dallwitz 1992 onwards; Clifford & Bostock, 2007). *Tripogon loliiformis* was described by Mueller (1873). The word *loliiformis* is derived from the Latin words *lolium* and *forme*, meaning "resembling *Lolium*" (Clifford & Bostock, 2007), owing to the resemblance of the inflorescences to those of the genus *Lolium*. *Tripogon loliiformis* is commonly called "five-minute grass" or "eight-day grass" due to its resurrection capability, or "rye beetle grass" due to the resemblance of the inflorescences to those of ryegrass (*Lolium* sp.) (Palmer & Weiller, 2005).

Tripogon is a genus of 45 species in the subfamily Chloridoideae, family Poaceae (The Plant List, 2015) (TABLE 1). Numerous genera in this subfamily are agronomically important grasses, such as finger millet (*Eleusine coracana*) and teff (*Eragrostis tef*) whilst others are used as livestock feed and 'famine food' such giant rat's tail grass (*Sporobolus pyramidalis*) (Van den Borre & Watson, 1997; Asfaw & Tadesse, 2001; Balemie & Kebebew, 2006). Some lawn grasses belong to this subfamily, for example, Bermuda or dog's tooth grass (*Cynodon dactylon*) and Zoysia grasses (*Zoysia japonica*, *Z. matrella*, *Z. tenuifolia*) (Beard & Green 1994; Wang et al., 2001). None of the species of *Tripogon* are considered agronomically important, however several species of *Tripogon* from India are of cultural and ritualistic significance or used as fodder for domesticated animals and material for thatching (Ragupathy et al., 2009; Newmaster & Ragupathy, 2010). *Tripogon loliiformis* is eaten by kangaroos and, in Central Australia, forms an important and almost exclusive part of kangaroo diet after rains (Low et al., 1973). Horses and sheep are also known to feed on it, but the foliage is too short for cattle grazing (Low et al., 1973).

Much of the information on the distribution, habitat and habit of different species in the genus *Tripogon* presented here has been compiled from a variety of sources, such as taxonomic revisions (e.g., Phillips & Launert, 1971; Phillips & Chen, 2002), regional floras (e.g., Palmer & Weiller, 2005; Potdar et al., 2012) and online databases (e.g., Watson and Dallwitz 1992 onwards; Clayton et al., 2006 onwards; Simon & Alfonso, 2011; Simon et al., 2011) (TABLE 1). The genus *Tripogon* occurs

TABLE 1. A summary of the synonyms, global distribution, preferred habitat and desiccation tolerance capability of the species included in the genus *Tripogon*.

Species	Synonyms	Distribution	Habitat	Desiccation tolerance
Tripogon africanus (Coss. & Durieu) H.Scholz & P.König	*Arcangelina africana, Kralikella africana, Kralikia africana, Oropetium africanum*	Arabian Peninsula (Saudi Arabia)	Unknown	Unknown
Tripogon anantaswamianus Sreek., V.J.Nair & N.C.Nair	None	Asia (India)	Swamp	Unknown
Tripogon borii Kabeer, V.J.Nair & G.V.S.Murthy	None	Asia (India)	Unknown	Unknown
Tripogon capillatus Jaub. & Spach.	None	Asia (India)	Unknown	Yes (Gaff & Bole, 1986)
Tripogon chinensis (Franch.) Hack.	*T. coreensis*	Asia (China, Korea, Russia, Mongolia, Philippines)	Dry stony slopes above river; marshland	Unknown
Tripogon copei Newmaster, V. Balas., Murug. & Ragup. ex Newmaster, V. Balas., Murug. & Ragup.	*T. cope*	Asia (India)	Moist shoal border, on rocks	Unknown
Tripogon curvatus S. M.Phillips & Launert	None	Africa (Kenya, Ethiopia)	Seasonally wet rocky outcrops	Yes (Gaff, 1986)
Tripogon debilis L.B.Cai	None	Asia (Western China)	Roadside; wasteland; stony slope	Unknown
Tripogon filiformis Nees ex Steud	*Nardurus filiformis, T. exiguus, T. javanicus, T. semitruncatus, T. unidentatus*	Asia (Bhutan, China, India, Indonesia, Mynmar, Nepal, Pakistan)	Dry grassy slopes, often among rocks	Yes (Gaff & Bole, 1986)
Tripogon humilis H.L. Yang	None	Asia (China)	Mountain slopes	Unknown
Tripogon jacquemontii Stapf	None	Asia (India)	Unknown	Yes (Gaff & Bole, 1986)
Tripogon larsenii Bor	None	Asia (India, Thailand),	Open sandstone plateau	Unknown
Tripogon leptophyllus (A.Rich.) Cufod.	*Danthonia leptophylla*	Africa (Eritrea, Ethiopia, Sudan)	Upland moist grassland, in rock crevices near rivers	Yes (Gaff, 1986)
Tripogon liouae S.M. Phillips and S.L. Chen	None	Asia (China)	Dry open spaces, sometimes forming a turf	Unknown
Tripogon lisboae Stapf	None	Asia (India)	Unknown	Yes (Gaff & Bole, 1986)
Tripogon loliiformis (F.Muell.) C.E.Hubb.	*Diplachne loliiformis Festuca loliiformis*	Australia (except Tasmania), New Guinea (Sogeri)	Granitic outcrop, mountain slopes, mulga vegetation	Yes (Gaff & Latz, 1978)

Species	Synonyms	Distribution	Habitat	Desiccation tolerance
Tripogon longiaristatus Hack. Ex Honda	None	Asia (China, Japan, Korea)	Rocky slopes	Unknown
Tripogon major Hook.f.	*T. liebenbergii, T. snowdenii, T. unisetus*	Africa (Cameroon Republic, Ethiopia, Malawi, Sierra Leone, Sudan, Tanzania, Uganda)	Rock crevices; hollows on flat rocks, in thin soil overlying lava on moist mountains, especially near summits	Yes (Gaff, 1986)
Tripogon minimus (A.Rich.) Hochst. ex Steud.	*T. abyssinicus, T. calcicola, Festuca minima, T. humbertianus, T. mandrarensis*	Tropical Africa, (excluding Burkina Faso, Cameroon Rep., Cape Verde Isl., Central Afr. Republic, Eritrea, Ethiopia, Ghana, Gambia, Kenya, Madagascar, Malawi, Mauritania, Mozambique, Niger, Nigeria, Senegal, Sudan, Tanzania, Zambia	Deciduous bushland, wooded or open grassland, seasonally wet rocky outcrops	Yes (Gaff, 1986)
Tripogon modestus S.M.PhillipsLaunert	None	Africa (Angola, Malawi)	Soil-pockets in rocky outcrops, around boulders in seasonally wet grassland	Yes (Gaff 1986)
Tripogon montanus Chiov.	None	Africa (Ethiopia, Sudan, Uganda), Arabian peninsula (Yemen)	Upland grassland, in rock-crevices, among boulders	Yes (Gaff 1986)
Tripogon multiflorus Miré & H.Gillet	*T. tibesticus*	Africa (Eritrea, Kenya, The Chad), Arabian Peninsula (Saudi Arabia)	Upland grassland, in seasonally wet places among rocks	Yes (Gaff 1986)
Tripogon nanus Keng f.	None	Asia (China)	Unknown	Unknown
Tripogon narayanae Sreek., V.J.Nair & N.C.Nair	None	Asia (India)	Swamp	Unknown
Tripogon nicorae Rúgolo & A.S.Vega	None	South America (Argentina, Bolivia, Chile, Ecuador, Peru)	On rocky slopes, prairies	Unknown
Tripogon oliganthus Cope	None	Arabian Peninsula	Unknown	Unknown
Tripogon polyanthus Naik & Patunkar	None	Asia (India)	Unknown	Unknown
Tripogon pungens C.E.C. Fisch.	None	Asia (India)	Unknown	Unknown
Tripogon purpurascens Duthie	*T. hookerianus*	Asia (Afghanistan, Bhutan, China, Nepal, India, Pakistan, Thailand), Arabian Peninsula (Saudi Arabia, Oman, Yemen)	*Open areas on sandstone rock formations, open stony mountainsides*	Unknown

Species	Synonyms	Distribution	Habitat	Desiccation tolerance
Tripogon ravianus Sunil & Pradeep	None	Asia (India)	Unknown	Unknown
Tripogon rupestris S.M.Phillips & S.L.Chen	None	Asia (China, India, Nepal)	Damp rocks	Unknown
Tripogon siamensis Bor	None	Asia (India, Thailand)	On rocky ground along edge of evergreen forest	Unknown
Tripogon sichuanicos S.M.Phillips & S.L.Chen	None	Asia (China)	Mountain slopes and dry valleys	Unknown
Tripogon sivarajanii Sunil	None	Asia (India)	Unknown	Unknown
Tripogon spicatus (Nees) Ekman	*Bromus spicatus, Diplachne reverchonii, D. spicata, Leptochloa spicata, Rabdochloa spicata, Sieglingia schaffneri, S. spicata, Tricuspis simplex, Triodia schaffneri, Triplasis setacea*	North America (USA), Central America, South America (Venezuela, Brazil, Ecuador, Bolivia, Paraguay, Uruguay, Argentina)	In low prairies, in clay, basaltic or saline soils, savannas, xerophytic regions, rocky slopes	Yes (Gaff, 1987)
Tripogon subtilissimus Chiov.	None	Africa (Kenya, Somalia), Arabian Peninsula (Saudi Arabia, Yemen)	Seasonally wet alkaline soils, especially on limestone and gypsum	Yes (Gaff 1986)
Tripogon thorelii A.Camus	None	Asia (Laos, Thailand)	Exposed rocky outcrop, on sandstone bedrock savannah, deciduous dipterocarp forest	Unknown
Tripogon trifidus Munro ex Stapf	None	Asia (Bhutan, China, India, Mynmar, Nepal, Thailand, Vietnam)	Stony ground, among rocks, in the open or in shade of broad-leaved mountain forest, trailsides, in or near rivers, waterfalls	Unknown
Tripogon vellarianus A.K.Pradeep	None	Asia (India)	Unknown	Unknown
Tripogon velliangeriensis	None	Asia (India)	Unknown	Unknown
Tripogon wardii Bor	None	Asia (China, India, Myanmar)	On rocky slopes	Unknown
Tripogon wightii Hook.f.	None	Asia (India)	On rocks of ca. 1500 m above sea level	Unknown
Tripogon yunnanensis J.L.Yang ex S.M.Phillips & S.L.Chen	T. yunnanensis	Asia (China)	Dry mountain slopes, among rocks	Unknown

in tropical, subtropical and warm temperate regions of Africa, Asia, Australia, North America and South America. Some species have a narrow geographic range (e.g., *T. copei, T. oliganthus, T. sichuanicos)* whilst others have much wider geographic ranges (e.g., *T. filiformis, T. minimus, T. spicatus*). Plants in this genus thrive in a variety of habitats, such as dry, seasonally moist, or moist mountains and lowlands. All species in the genus *Tripogon* occur in clumps or tufts ranging in height from 4 cm (e.g., *T. loliiformis*) to 90 cm (e.g., *T. jacquemontii*). Fourteen species in the genus *Tripogon* are desiccation-tolerant (Gaff, 1977; Gaff, 1986; Gaff, 1987; Gaff & Bole, 1986; Gaff & Latz, 1978; Iturriaga et al., 2000) (TABLE 1). Whether the ability to tolerate extreme desiccation occurs in other species of *Tripogon* is not known. All species tested have shown to be desiccation-tolerant and there are no known reports of desiccation-sensitive species (Gaff, pers. comm.).

HABITAT AND FIELD ECOLOGY OF *T. LOLIIFORMIS*

Tripogon loliiformis occurs in a variety of habitats with shallow and rapidly drying soils (FIG. 2). It commonly occurs on rocky outcrops (inselbergs) and open vegetation where it is usually restricted to shallow soil platforms overlying rocks (Hunter & Clarke, 1998; Just & Evans, 2010). It is found in mulga vegetation (community of small *Acacia* trees forming a dense scrub in dry inland areas of Australia), which is considered to be a drought

FIG. 2. Examples of some of the different types of habitats in which *T. loliiformis* occurs. Arrows indicate location of plants. A & B: Granite outcrop with a narrow band of *T. loliiformis* (Mt Magnet, Western Australia); C: Eucalypt woodland with rocky boulders (White Rock Conservation Park, Queensland); D & E: Shallow soil platform overlying rhyolite rocks (Wildhorse Mountain, Queensland); F: Open eucalypt woodland with sandy soil on floodplain (Eidsvold, Queensland); G: Pisolitic (pea like) laterite soil layer (Paynes Find, Western Australia); H: Gravelly soil (Dangore, Queensland); I: Gravelly soil overlying rock platforms (Myall Park Botanic Gardens, Queensland).

refuge for native and non-native herbivores (Low et al., 1973; Roberts, 1978). It is also found in depressions and creek lines on gibber plains with chenopods, on basalt plains or on flood plains in open eucalypt woodland with a grassy understory (Rogers & Stride, 1997; Hunter & Clarke, 1998; McGann et al., 2001; Palmer & Weiller, 2005).

We consider *T. loliiformis* to have a restricted, but common, distribution as we have observed it growing in very specific habitats where it is locally abundant (FIG. 2). In areas with large granitic outcrops, such as in the Wheat Belt in Western Australia, *T. loliiformis* often forms a distinctive band following the contour of the rock (FIG 2A, B). The extremely shallow soil closest to the bare rock is colonised by mosses and lichen. A short distance from the bare rock there is a slight build up of soil, and this is where clumps of *T. loliiformis* occur, often intermingled with other desiccation-tolerant plants, such as mosses (e.g., *Tortula* sp.) and ferns (e.g., *Cheilanthes* sp.) Further away from the bare rock, where the soil is still deeper, we have observed taller grasses (e.g., *Borya* sp., *Eragrostis* spp.), sedges (*Fimbristylis* spp.) and drought-tolerant annual or short-lived perennial plants (*Calandrinia* sp. and *Chrysopogon* sp.). As the abundance of these taller plants increases, the occurrence of *T. loliiformis* decreases. These observations are consistent with those for resurrection plants in general, which tend to grow on shallow soils overlying rock slabs or soils that collect in depressions on rock outcrops (Gaff 1977; Porembski & Barthlott, 2000). It is generally well established that resurrection plants are important pioneer species on shallow soil, particularly when water is limited (Gaff & Latz, 1978). Studies on the pattern of species replacement during succession on rocky outcrops have shown that the change is due to the development of a complex soil depth gradient involving changes in temperature, soil depth and water-holding capacity (e.g., Keever et al., 1951; Uno & Collins, 1987).

Our observations have led us to speculate that the locally abundant but restricted zone to which *T. loliiformis* is confined could be due to the inability of other angiosperms to survive the rapid and repeated drying that is common in extremely shallow soils. It is possible that *T. loliiformis* could survive in deeper soils but gets outcompeted by other plants, some of which are also desiccation-tolerant plants (*Borya* sp., *Eragrostiella* sp.). Gaff & Oliver (2013) have suggested that low growing resurrection plants are the first plants to colonise bare soils and with the accumulation of additional soil and detritus, taller desiccation-tolerant plant species get established, eventually followed by larger desiccation-sensitive species that overshadow and out-compete the desiccation-tolerant plants. This scenario has been called the 'productivity trade off' hypothesis, and suggests that the ability to tolerate desiccation entails costs that constrain productivity (e.g., Oliver et al., 2000). Desiccation-tolerant species could be competitively inferior to desiccation-sensitive species in habitats where the latter can grow (Alpert, 2000), but this has yet to be explicitly tested in the case of *T. loliiformis.*

Our field observations indicate that *T. loliiformis* is sensitive to disturbance, such as trampling by cattle and goats, scraping and digging by rabbits, vehicular activity, rock excavation (e.g., granite) and dumping of rubbish (FIG. 3). In otherwise suitable habitats, *T. loliiformis* does not seem to survive in the presence of any one of these disturbances. A decrease in the abundance of *T. loliiformis* in the presence of grazing stock has been previously documented (Just & Evans, 2010). Field experiments, such as exclusion studies, are needed to test the sensitivity of *T. loliiformis* to different types and regimes of disturbance. Even though *T. loliiformis* itself is not a threatened species, elements of the associated flora and fauna are often restricted in distribution. This is especially true where *T. loliiformis* forms part of a rare inselberg flora that requires conservation and protection (e.g., Burke, 2003; Larson, 2001; Jocqué et al., 2007; Porembski, 2007; Michael et al., 2008; Bayliss et al., 2014). It is possible that *T. loliiformis* could serve as an indicator species for monitoring disturbances in inselberg ecosystems given its local abundance but sensitivity to disturbance.

Whilst research has not been conducted on the response of *T. loliiformis* to natural disturbances, it appears to cope with repeated fires (Just & Evans, 2010). We have observed new growth emerging from clumps of charred plants in open eucalypt woodland with shallow soil platforms overlying rocks. The presence of shoot meristems on or just under the soil that can be protected from direct light and fire is characteristic of desiccation-tolerant plants (Gaff & Oliver, 2013). Our observations of post-fire resprouting of *T. loliiformis* indicate a similar placement of meristematic tissue, but this needs to be confirmed by histological investigations. We do not know if the ability of *T. loliiformis* to tolerate natural

disturbances, such as grazing and fire, varies within the species and whether populations growing in less disturbance-prone areas are better able to cope with disturbances in comparison to populations growing in areas with frequent disturbances. Inselberg flora is generally more sensitive to fire than that of the surrounding matrix (Hunter, 2003) but whether this holds true for *T. loliiformis* remains to be tested.

In species growing on inselbergs and the surrounding matrix, individuals from inselbergs have a higher degree of desiccation tolerance than those growing in the deeper soil of the surrounding matrix (Chapman & Jones, 1975). Differences have also been observed in other habitats and different species, for example, *Sporobolus fimbriatus* is a grass that contains both desiccation-tolerant and -sensitive populations (Gaff, 1986), and different degrees of desiccation tolerance have been observed in individuals from a single population of *Borya nitida* (Gaff, 1981), but this does not seem to be the case for *T. loliiformis.* Gaff & Latz (1978) tested individuals of *T. loliiformis* from different habitats and with different morphology (glabrous and hairy forms) and all proved to be equally desiccation-tolerant. The ability to tolerate desiccation could be associated with the ability to tolerate various other types of environmental stresses (Alpert, 2000), however, Wood & Gaff (1989) found no evidence that desiccation tolerance was associated with salt tolerance in the grass genus *Sporobolus.* Whether *T. loliiformis* is also salt-tolerant has not been studied but some populations occur close enough to coastal areas to get exposed to salt spray (e.g., Emu Mountain, Queensland, FIG. 4A & B). The link, if any, between desiccation tolerance and tolerance to other environmental stresses (e.g., disturbance, salinity, heat) in *T. loliiformis* remains uncertain. Along similar lines, another equally interesting question that is yet to be addressed is whether populations of *T. loliiformis* from the island of New Guinea, which has very different climatic conditions from that of mainland Australia, are also desiccation-tolerant or not.

HABIT (GROSS MORPHOLOGY) OF *T. LOLIIFORMIS*

In its natural habitat and when sufficient water is available, individual plants of *T. loliiformis* form distinct green clumps (FIG. 2E). The leaves of *T. loliiformis* respond to desiccation by characteristic folding of the flat green leaves to filiform (bristle-

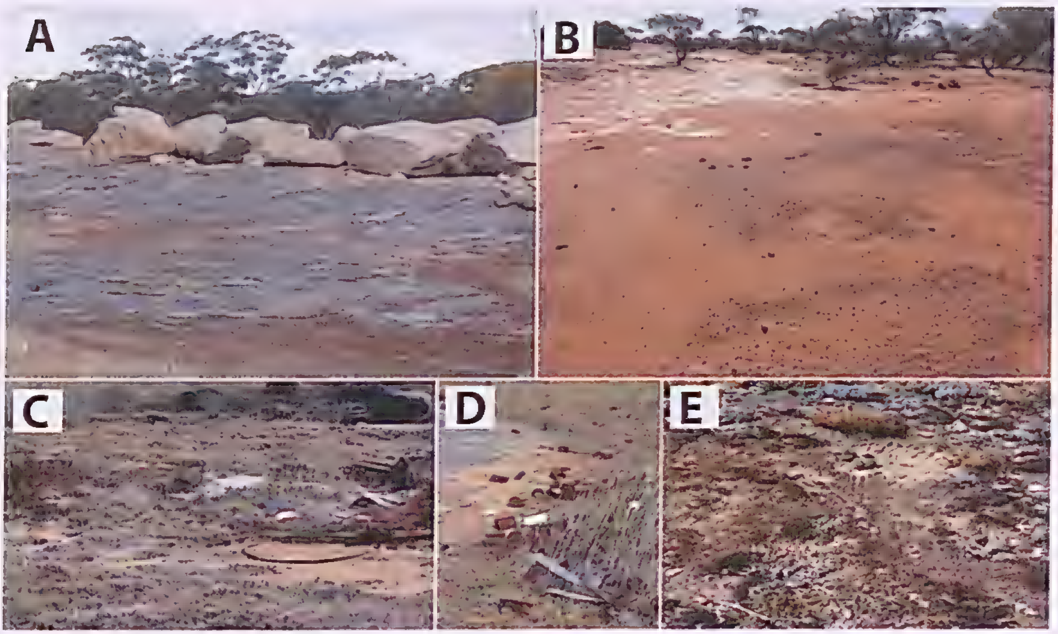


FIG. 3. Examples of disturbances in habitats that are otherwise suitable for *T. loliiformis*. A: Rock excavation; B: Trampling by cattle; C & D: Dumping of garbage; E: Scraping and digging by rabbits.

like) purplish or dark-brown pigmented leaves. Plants at different stages of desiccation can be observed in the field over a small spatial scale. At the onset of a dry period, plants growing closer to a rocky outcrop in shallow soil will become fully desiccated well before those growing further away in slightly deeper soil (FIG. 4C). In extremely dry conditions, most of the leaves in a clump appear straw-coloured and are dead (senesced) whilst only a few leaves within each clump are pigmented (deep maroon) and desiccation-tolerant (FIG. 4D).

When subjected to water stress, the desiccation response (pigmentation and folding) is first observed at the tip of the leaf and gradually spreads towards the base. Quite often the tips of pigmented leaves appear to have senesced. When water becomes available, the pigmented leaves start unfolding and turning green. This change starts from the base of the leaf and proceeds towards the tip (FIG. 4E). The first signs of greening of pigmented leaves in *T. loliiformis* can appear within a few minutes, but it usually takes a few hours (12-24 hours) for an entire leaf to become green again and a number of days (5-15 days) before new growth is produced (FIG. 4F). These different stages of recovery from the desiccated state are probably responsible for the two different time-related common names for this species (five-minute grass and eight-day grass).

In some grasses desiccation tolerance is confined to the basal portion (meristematic zone) of the leaf (e.g., *Eragrostis hispida, Borya scirpoides*) whilst in closely related species the entire leaf is tolerant (e.g., *Eragrostis nindensis, Borya nitida*) (Gaff & Ellis, 1974; Gaff & Oliver, 2013). Comparable differences in other species of *Tripogon* or closely related genera have not been documented. Whether there is a gradual evolutionary change from a restricted zone of desiccation-tolerant tissue to an entire leaf that is desiccation-tolerant could be tested in a phylogenetic context by studying character evolution within a clade of grasses containing species with different degrees of desiccation tolerance. Detailed observations on the age of leaves that exhibit desiccation tolerance

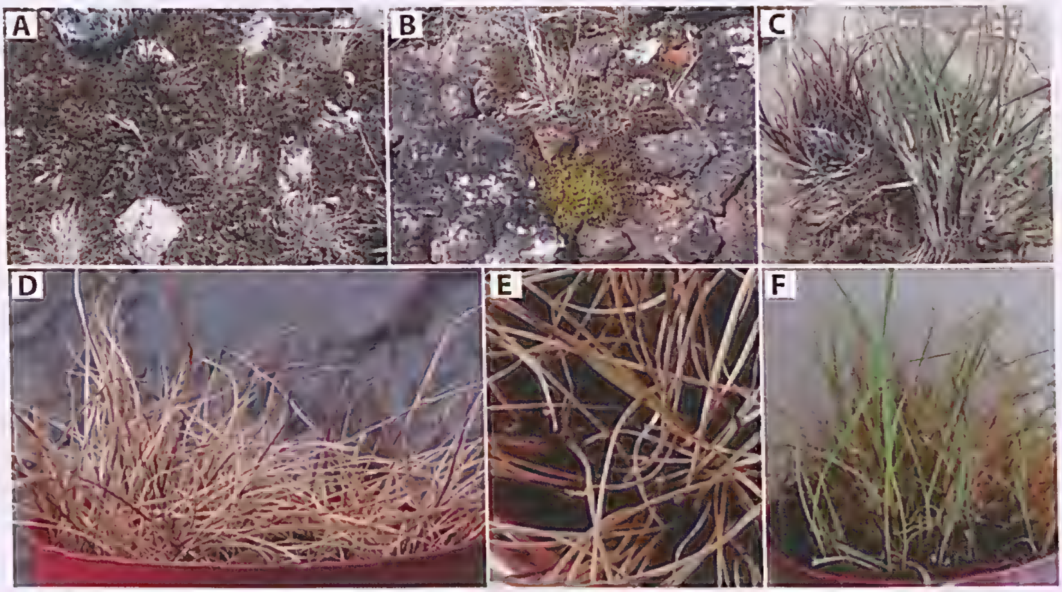


FIG. 4. Desiccation tolerance in *T. loliiformis*. A & B: An illustration of the much more rapid response of mosses to the availability of water (< 2 minutes) than other desiccation-tolerant plants, such as ferns (*Cheilanthes* sp.) and *T. loliiformis* (Emu Mountain, Queensland); C: Hydrated plants with green leaves and desiccated plants with pigmented leaves (Karomin Rock, Western Australia); D-F *Ex situ* plants (Bruce Rock, Western Australia), D: Desiccated plant with a few pigmented leaves intermingled with dead leaves before watering; E: *Ex situ* plant 10 minutes after watering showing gradual greening of a desiccation-tolerant pigmented leaf from the base towards the tip; F: The same *ex situ* plant 12 days after the start of watering showing full recovery from desiccation and the start of new growth.

in *T. loliiformis* are lacking, but there is a general tendency for plant cells to lose the ability to tolerate desiccation as they age (Alpert, 2000). Observations of a different grass, *Sporobolus stapfianus*, by Gaff & Giess (1986) showed that recently matured leaves survive desiccation entirely, whereas in older leaves, the tissue at the tip of the leaves dies. We have observed a similar pattern in *T. loliiformis*. Griffiths et al. (2014) have suggested that desiccation tolerance of leaf tissue has an age-specific component and genes associated with repression of drought-induced senescence are not expressed in older leaves. The gene expression for the senescence pattern we have observed in *T. loliiformis* is not known, but a similar mechanism is quite probable. Detached desiccated leaves of *S. stapfianus* can remain in an anabiotic state for two years (Gaff & Ellis, 1974). An interesting aspect of desiccation tolerance in grasses that has not been investigated in detail is how long these plants can remain in a desiccated state and still rehydrate and be fully resurrected. A test of the resurrection capacity of herbarium specimens, of varying preservation ages, could shed further light in this context

We have observed the unfolding and gradual greening of pigmented leaves in the presence of dew, indicating that water can be absorbed directly by leaves. We assume entry of water is from epidermal hairs, but this needs to be tested by histological examination. Physiological studies on transpiration rates and relative water content of leaves have also pointed to dew absorption as a possible mechanism for uptake of water (Olsen, 1983). However, to restore full physiological function, uptake of water from the soil by the root system would be required to ensure continuity of water flow through the entire vascular system.

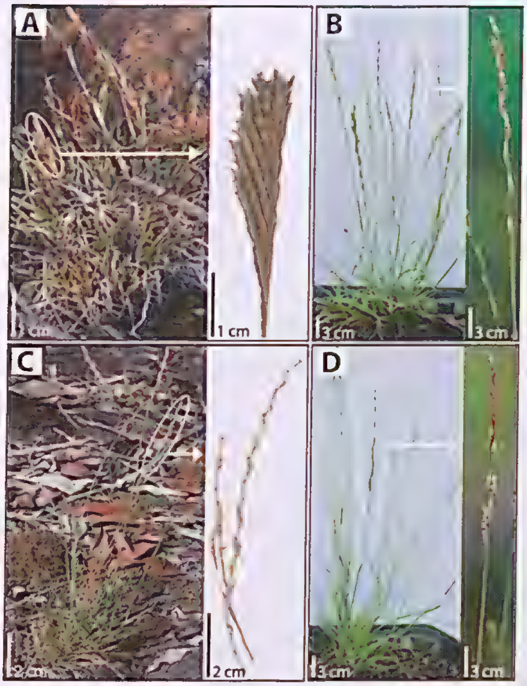


FIG. 5. Phenotypic plasticity in vegetative and reproductive structures in *T. loliiformis*. A: *in situ* plant from Western Australia with small leaves and a short, compact inflorescence; B: *ex situ* plant from Western Australia with longer leaves and a tall, uncompressed inflorescence; C: in situ plant from southeast Queensland with long leaves and a tall, uncompressed inflorescence; D: *ex situ* plant from southeast Queensland with the same morphology as that of the *in situ* counterpart.

The roots of *T. loliiformis* growing on rock platforms or shallow soils form a short dense clump. When plants from these habitats are grown in deeper soil (e.g., in pots,), a much longer root system develops. Whilst the vegetative shoots of most desiccation-tolerant grass species are short and do not change with increase in soil depth, some grasses, such as *Microchloa caffra* and *Eragrostis invalida,* can grow significantly taller when grown in deeper soils (Gaff & Oliver, 2013). We have observed similar changes, not only in root length but also in plant height and leaf length. After a year of growth in pots in Brisbane (Queensland), field-collected plants from Western Australia were indistinguishable in vegetative morphology from the naturally taller plants from southeast Queensland (FIG. 5). Interestingly, there was no noticeable change in the morphology of the plants from southeast Queensland when grown in pots. This is the first report of phenotypic plasticity in *T. loliiformis* (see reproductive biology below for more on plasticity).

LEAF STRUCTURE OF *T. LOLIIFORMIS*

As far as we are aware, Olsen (1983) is the only investigation to date to have examined leaf anatomy of *T. loliiformis* using light microscopy (LM) and ultrastructure studies using transmission electron microscopy (TEM). Detailed descriptions of the structure of leaves in *T. loliiformis* and other species in the genus and the methodology used are available in Fabillo (2015). We present our own observations on anatomical differences between hydrated and field-desiccated leaves using LM and leaf surface micromorphology using scanning

electron microscopy (SEM) and report on major ultrastructural observations from Olsen (1983).

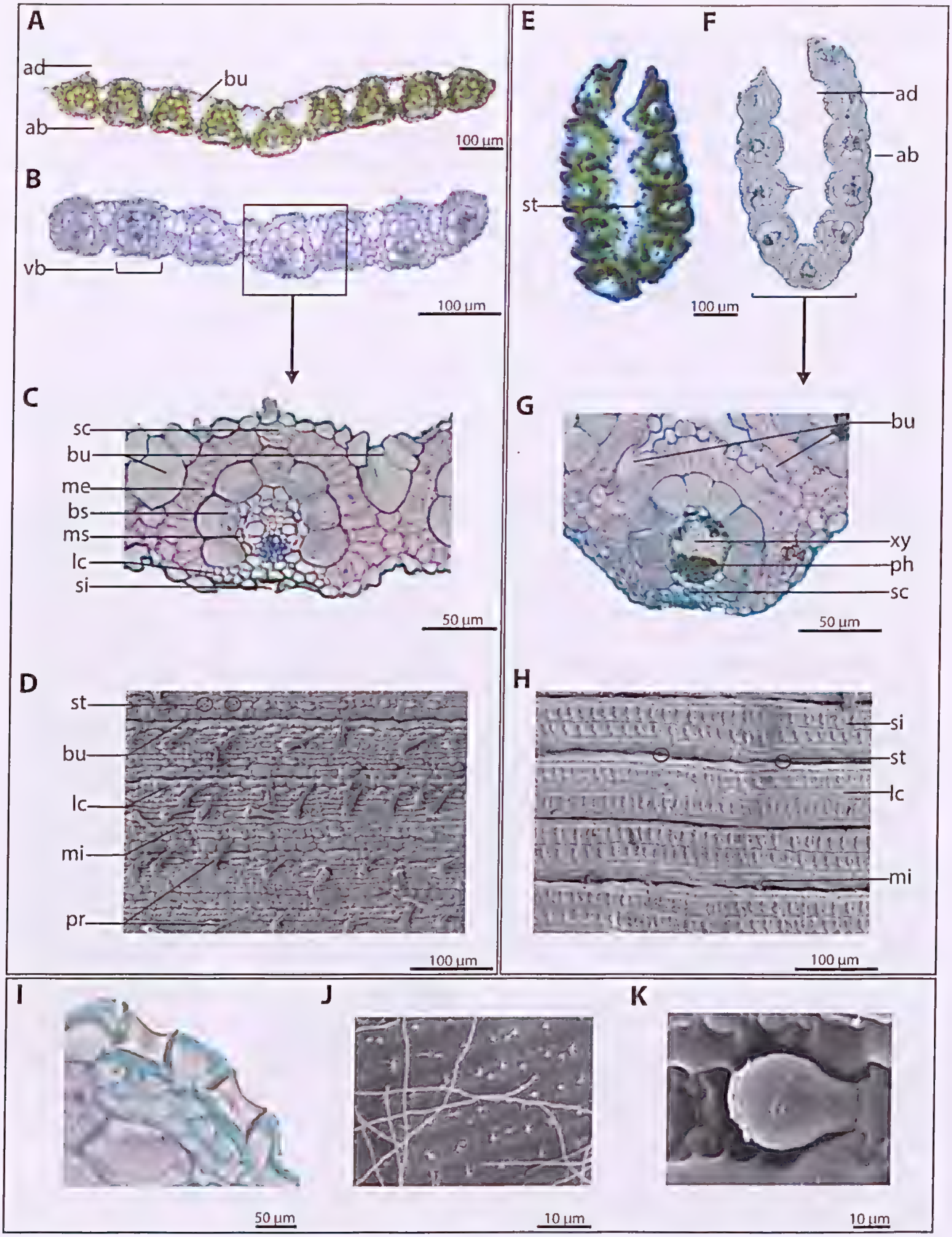
The parallel venation, typical of grass leaves, produces conspicuous alternating costal (above veins) and intercostal (in between veins) zones on both abaxial and adaxial surfaces of *T. loliiformis* (FIG 6). Cells in the costal zone include long cells, short cells (undifferentiated and specialized, such as silica cells), prickles and macro-hairs, while those in the intercostal zone include long cells, bulliform cells, stomata, micro-hairs and macro-hairs. The distribution of cells in these zones is similar on the abaxial and adaxial surfaces, except for the higher density of hairs on the adaxial surface and the absence of papillae on long cells on the abaxial surface. Transverse sections of the leaf blade show the characteristic Kranz anatomy typical of grasses with C_4 photosynthesis, and in particular those with the NAD-ME pathway (Prendergast et al., 1987). This consists of a mestome sheath surrounding each vascular bundle, large prominent bundle-sheath cells with centripetally arranged chloroplasts and mesophyll cells arranged in an arc around the bundle sheath (FIG. 6C). The general anatomy and micromorphology of the leaves of *T. loliiformis* is consistent with that of other desiccation-tolerant vascular plants that have various mechanisms for reducing transpiration rates and protecting cellular contents from the harmful effects of free radicals. Such mechanisms include light-scattering epidermal hairs or scales, epidermal pigments, sunken stomata and foliage that can curl, fold or roll up. However, we were surprised to find stomata located on the abaxial surface, which remain exposed to the dry air unlike those on the adaxial surface that get protected when the leaf folds up (FIG. 6H). Whether the abaxial stomata remain physiologically active and there is loss of water through transpiration during the desiccated phase needs further investigation.

Hydrated leaves are green in colour and flat in outline (FIG. 6A, B). Desiccated leaves are dark maroon to purple in colour and U-shaped (folded) in outline (FIG. 6E, F). Anatomically, the most obvious difference between desiccated and hydrated leaves is the presence of pigments (anthocyanins) in epidermal cells, other than silica cells, on the abaxial surface (FIG. 6E). The epidermal cells of the adaxial surface are less heavily pigmented. Cells at the tips of the folded leaf that appear to be more exposed to the environment have more pigmentation than those deep inside the folded area, where pigmentation is seen mainly in guard cells (FIG. 6E). A notable difference is in the shape of bulliform cells, which appear turgid and fully distended when hydrated (FIG. 6C) but flaccid and collapsed when desiccated (FIG. 6G). In surface view, the intercostal zones are no longer visible due to the shrinkage of bulliform cells (FIG. 6D, H). Other easily observable differences include the disintegration of the large central vacuoles in the bundle sheath cells (FIG. 6G). Contrary to what is commonly stated in the literature on anatomical studies of desiccation-tolerant plants (e.g., Bartley & Hallam, 1979; Hallam, 1976; Willigen et al., 2003), our investigations clearly demonstrate that it is possible to study leaf anatomy by modifying standard histological processes (resin- and paraffin-embedding in this case) without creating artefacts, such as rehydrating desiccated leaves or dehydrating hydrated leaves during the sample preparation process. This opens up the potential for further research on the anatomy of desiccation-tolerant plants using light microscopy.

An examination of the ultrastructure of mesophyll cells by Olsen (1983) indicates that in desiccated leaves the cell walls become convoluted, plastoglobuli are produced and some degree of chloroplast vesiculation takes place but the thylakoid membranes remain intact. These changes are reversed within two hours of rehydration (Olsen, 1983). This is further confirmed by physiological studies that show that chlorophyll pigments are retained in this species during desiccation (Gaff & Latz, 1978) and by the pattern of physiological recovery (chlorophyll levels and photosynthetic activity) in *T. loliiformis* (Olsen, 1983). These observations are typical of other desiccation-tolerant plants in response to stress (e.g., Hallam & Gaff, 1978; Gaff et al., 2009; Bartels & Hussain, 2011) and indicate that *T. loliiformis* is a chlorophyll-retaining or homoiochlorophyllous species (Tuba *et al.*, 1998). Our own observation of the short duration of time required for rehydration in *T. loliiformis* is typical of homoiochlorophyllous plants (Bartels & Hussain, 2011) and has been verified physiologically in other desiccation-tolerant grasses that become fully green within 24 hours of rehydration (Gaff & Ellis, 1974).

LIFE HISTORY AND REPRODUCTIVE BIOLOGY OF *T. LOLIIFORMIS*

Flowering in *T. loliiformis* occurs throughout the year. The inflorescence of *T. loliiformis* is a solitary raceme with bisexual spikelets (FIG. 5, 7A-C).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The length of inflorescence varies from 2 – 22 cm, with 5 – 30 spikelets per inflorescence and 5 – 28 florets in each spikelet. Each floret has a lemma with a tuft of hairs located at the base of three veins. These structures form the basis of the name of the genus from the Greek words *treis* (three) and *pogon* (beard/tuft) (FIG. 7D). Detailed descriptions of the inflorescence morphology of *T. loliiformis* and other species of *Tripogon* are available elsewhere (Fabillo, 2015). Grass taxonomy relies heavily on inflorescence morphology and the differences in the arrangement and density of spikelets, along with differences in vegetative morphology, has led others to speculate that morphologically different plants from different parts of Australia could be different species (Gaff & Latz, 1978; Olsen, 1983; Palmer & Weiller, 2005). Plants from southeast Queensland have long inflorescence with non-overlapping, short spikelets and a few florets per spikelet (FIG. 7A); those from central Queensland have long inflorescences with overlapping, long spikelets and numerous florets per spikelet (FIG. 7B); whilst those from Western Australia have short inflorescence with overlapping, long spikelets but fewer florets per spikelet than those from southeast Queensland. As we observed for vegetative structures, after a year of growth in pots in Brisbane (Queensland), the inflorescence morphology of plants from Western Australia had changed dramatically and was indistinguishable from that of plants from southeast Queensland (FIG. 5). The *ex situ* plants from southeast Queensland remained unchanged in both reproductive and vegetative morphology from their *in situ* condition. Our observations of phenotypic plasticity might explain why there was no phylogenetic support, based on analyses of morphological (non-sequence) or molecular (sequence) data, to split *T. loliiformis* into multiple species (Fabillo, 2015).

The only report on seed germination is for a population of *T. loliiformis* in Victoria. Just & Evans (2010) observed successful germination in trays but only around moss beds. We have successfully germinated seeds from different sites, e.g., Mt Magnet (Western Australia), Charleville (central Queensland) and Wildhorse Mountain (southeast Queensland). Germination has been successful on moist filter paper in petri dishes under laboratory conditions as well as in damp potting mix (FIG. 7E, F). Seed germination on moist filter can take as few as 3 days but in soil it takes longer (5-10 days). Seed viability is at least 12 months in laboratory conditions (Olsen, 1983). Details on life history traits, such as flowering pattern, seed production, germination rates, seedling survival and growth rates for any species of *Tripogon* are generally lacking.

Most publications refer to *T. loliiformis* and other species in the genus as annual or short-lived perennial plants. We question the applicability of terms "annual and perennial" in the conventional sense to a plant like *T. loliiformis* that might experience multiple and variable durations of growth followed by prolonged periods of time in the desiccation-tolerant phase. This issue has been considered in other contexts, such as the use of the terms monocarpic and polycarpic instead of semelparous and iteroparous respectively (see, for example, Young & Augspurger 1991; Amasino 2009; Bergonzi & Albani 2011). Whether the longevity of *T. loliiformis* is related to flowering and seed production is not clear. Does the term annual actually mean a 12-month life cycle? Or is the longevity of individual plants linked to a single or certain number of reproductive events that could occur within a relatively short period of time or could take a few years if suitable wet periods are infrequent and growth rates slow? Or does the longevity depend on the number of cycles of dehydration and rehydration experience by individual plants? Some desiccation-tolerant angiosperms are known to survive several cycles of dehydration and rehydration in a year, as for example 17 cycles in a year

FIG. 6. Anatomical differences between hydrated and desiccated leaves of *T. loliiformis*. The outline of leaves in transverse section is flat in hydrated leaves (A, B) and U-shaped in desiccated leaves (E, F); abaxial epidermis is colourless in hydrated leaves (A) and pigmented in desiccated leaves (E); bulliform cells are fully distended in hydrated leaves (C, D) and collapsed in desiccated leaves (G, H); a large central vacuole and centripetally arranged chloroplasts are visible in the bundle sheath cells of hydrated leaves (C) but no longer distinct in desiccated leaves (G); differences in appearance of costal and intercostal zones of hydrated (D) and desiccated leaves (H) due to the collapse of the bulliform cells in the latter. D, H – K: Characteristic structures seen in *T. loliiformis*, and differences in distribution of adaxial (D) and abaxial (H) surfaces. I: silica cells on abaxial surface; J: macro-hairs and prickles, K: bicellular micro-hair and long cells with sinuous cell walls. Techniques used A & E: free-hand sections of fresh leaves; B, C, E, F & I: microtome sections of resin-embedded samples stained with ruthenium red and TBO; D, H, J & K: Scanning electron microscopy. Abbreviations used: ab- abaxial; ad- adaxial; bu- bulliform cell; bs- bundle sheath cell; cl- chloroplasts; lc: long cell; ma- macro-hair; me- mesophyll cell; mi- micro-hair; ms- mestome sheath; sc- sclerenchyma fibres; sh- short cell; st- stomatal complex; ph- phloem tissue; pr- prickle; xy- xylem tissue.

in the perennial *Chamaegigas intrepidus* (Gaff & Giess 1986). The number of cycles that desiccation-tolerant plants can endure does not seem to be limited, provided there are periodic opportunities for photosynthesis (Gaff & Oliver, 2013), but the link between life cycle, frequency of reproductive events and the duration of active growth has not been investigated in *T. loliiformis*.

CONCLUDING REMARKS

Tripogon loliiformis provides an ideal system for testing numerous hypotheses about the ecology of desiccation-tolerant plants. Given the probable phylogenetic affinity of this genus with other resurrection grasses (e.g., *Eragrostiella* sp.), this larger clade provides an interesting group to study the

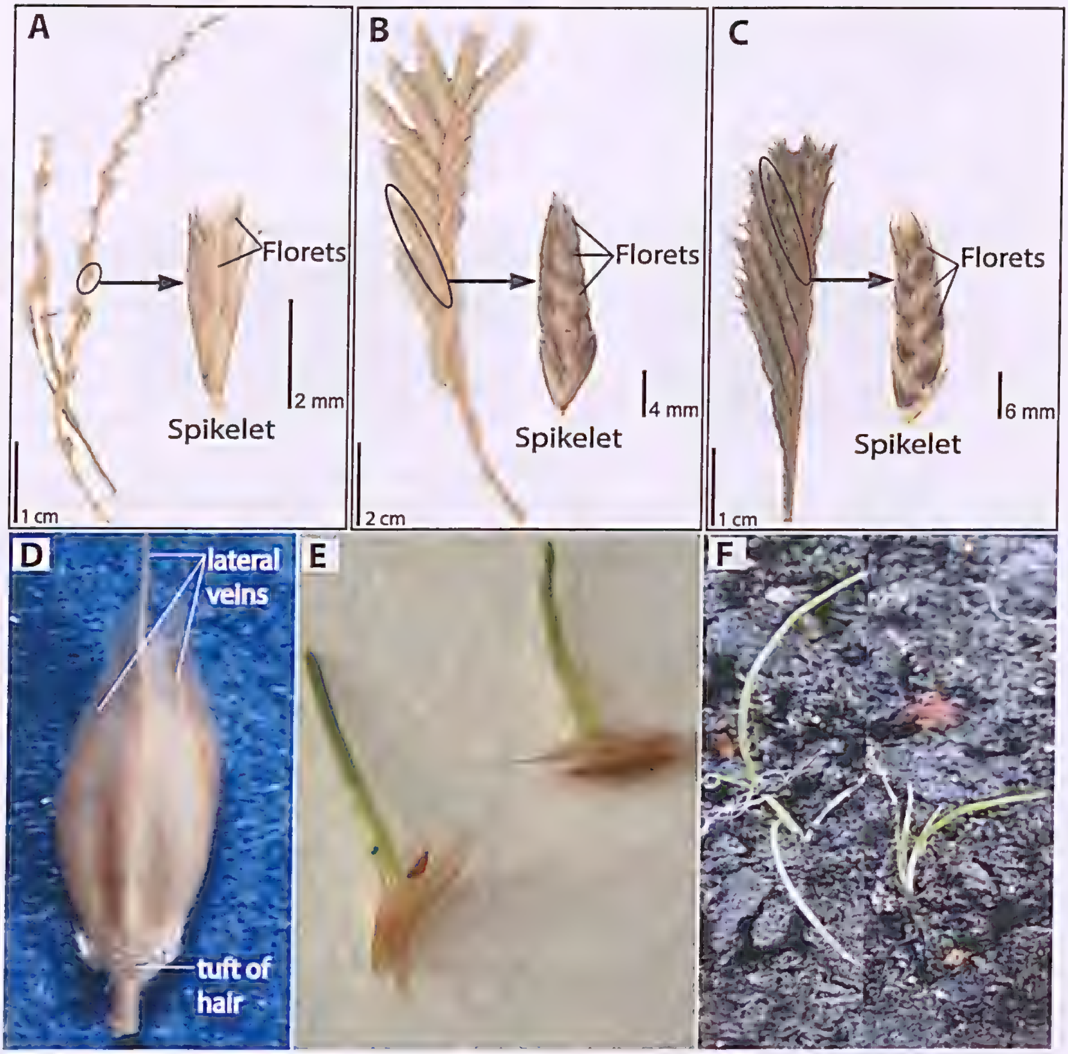

FIG. 7. Reproductive features of *T. loliiformis*. A – C: Morphologically different inflorescences and spikelets from different localities. A: Long inflorescence with non-overlapping, short spikelets and a few florets per spikelet (Wildhorse Mountain, Queensland); B: Long inflorescence with overlapping, long spikelets and numerous florets per spikelet (Mariala National Park, Queensland); C: Short inflorescence with overlapping, long spikelets but fewer florets per spikelet than those of B (Mt. Magnet, Western Australia); D: A single floret showing a lemma with three veins and a tuft of hairs at the base; E–F: Successful seed germination on damp paper in a petri dish and in damp potting mix.

evolution of desiccation tolerance and test hypotheses of single versus multiple origins of this trait and whether different mechanisms (at the morpho-anatomical, physiological or molecular/gene expression level) are involved. Although phylogenetic results do not provide support for splitting *T. loliiformis* into multiple species, the possibility of regional genotypic variation and associated differences in desiccation tolerance cannot be overlooked. The extensive morphological variation, lack of phylogenetic differentiation and indications of different degrees of phenotypic plasticity in a species with such a wide geographic distribution makes *T. loliiformis* an intriguing subject in need of further research.

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LITERATURE CITED

ALPERT, P. 2000. The discovery, scope, and puzzle of desiccation tolerance in plants. Plant Ecology 151: 5-17.

AMASIO, R. 2009. Floral induction and monocarpic versus polycarpic life histories. Genome Biology 10: 228.

ASFAW, Z. & TADESSE, M. 2001. Prospects for sustainable use and development of wild food plants in Ethiopia. Economic Botany 55: 47-62.

BALEMIE, K. & KEBEBEW, F. 2006. Ethnobotanical study of wild edible plants in Derashe and Kucha Districts, South Ethiopia. Journal of Ethnobiology and Ethnomedicine 2: 1-9.

BARTELS, D. & HUSSAIN, S.S. 2011. Resurrection plants: Physiology and molecular biology. Pp. 339-364. In Luttge, U., Beck, E. & Bartels, D. (eds), Plant Desiccation Tolerance. (Springer-Verlag, Berlin).

BARTLEY, K. & HALLAM, N.D. 1979. Changes in the fine structure of the desiccation-tolerant sedge, *Coleochloa setifera* (Ridley) Gilly, under water stress. Australian Journal of Botany 27: 531- 545.

BAYLISS, J., TIMBERLAKE, J., BRANCH, W., BRUESSOW, C., COLLINS, S., CONGDON, C., CURRAN, M., DE SOUSA, C., DOWSETT, R. & DOWSETT-LEMAIRE, F. 2014. The discovery, biodiversity and conservation of Mabu Forest-the largest medium-altitude rainforest in southern Africa. Oryx 48: 177-185.

BEARD, J.B. & GREEN, R.L. 1994. The role of turf grasses in environmental protection and their benefits to humans. Journal of Environmental Quality 23: 452-460.

BERGONZI, S. & ALBANI, M.C. 2011. Reproductive competence from an annual and a perennial perspective. Journal of Experimental Botany 62: 4415–4422.

BLOMSTEDT, C.K., GIANELLO, R.D., GAFF, D.F., HAMILL, J.D. & NEALE, A.D. 1998. Differential gene expression in desiccation-tolerant and desiccation-sensitive tissue of the resurrection grass, *Sporobolus stapfianus*. Functional Plant Biology 25: 937-946.

BURKE, A. 2003. Inselbergs in a changing world—global trends. Diversity and Distributions 9: 375-383.

CHAPMAN, R. H. & JONES, S. B. JR. 1975. Ecotypic differentiation in *Andropogon virginicus* (Gramineae). Bulletin of the Torrey Botanical Club 102: 166-171.

CLAYTON, W. D., M. S. VORONTSOVA, K. T. HARMAN, AND H. WILLIAMSON. 2006 onwards. *Tripogon*, GrassBase - The Online World Grass Flora. Accessed 29 June 2015 http://www.kew.org/data/grasses-db.html.

CLIFFORD, H.T. & BOSTOCK, P.D. 2007. Etymological Dictionary of Grasses. (Springer-Verlag Heidelberg).

FABILLO, M. 2015. Leaf and Inflorescence Structure and Phylogenetics of *Tripogon* and Affiliated Genera (Poaceae: Chloridoideae). Ph.D. Thesis. (Queensland University of Technology, Queensland).

FARRANT, J.M. 2000. A comparison of

mechanisms of desiccation tolerance among three angiosperm resurrection plant species. Plant Ecology 151: 29-39.

GAFF, D. 1971. Desiccation-tolerant flowering plants in southern Africa. Science 174: 1033-1034.

GAFF, D. 1977. Desiccation-tolerant vascular plants of southern Africa. Oecologia 31: 95-109.

GAFF, D. 1981. The biology of resurrection plants. Pp. 114-144. In Pate, J.S. & McComb, A.J. (eds), The Biology of Australian Plants. (University of Western Australia Press Western Australia).

GAFF, D. 1986. Desiccation-tolerant 'resurrection' grasses from Kenya and West Africa. Oecologia 70: 118-120.

GAFF, D. 1987. Desiccation-tolerant plants in South America. Oecologia 74: 133-136.

GAFF, D. 1989. Responses of desiccation-tolerant 'resurrection' plants to water stress. P. 308. In Kreeb, K, Richter H. & Hinckley, T. (eds), Structural and Functional Responses to Environmental Stress Vol. 581. (SPB Academic Publishing The Hague).

GAFF, D. & BOLE, P. 1986. Resurrection grasses in India. Oecologia 71: 159-160.

GAFF, D. & CHURCHILL, D. 1976. *Borya nitida* Labill.—an Australian species in the Liliaceae with desiccation-tolerant leaves. Australian Journal of Botany 24: 209-224.

GAFF, D. & ELLIS, R. 1974. Southern African grasses with foliage that revives after dehydration. Bothalia 11: 305-308.

GAFF, D.F., BLOMSTEDT, C.K., NEALE, A.D., LE, T.N., HAMILL, J.D. & GHASEMPOUR, H.R. 2009. *Sporobolus stapfianus*, a model desiccation-tolerant grass. Functional Plant Biology 36: 589-599

GAFF, D. & GIESS, W.1986. Drought resistance in water plants in rock pools of southern Africa. Dinteria 18: 17-37.

GAFF, D. & LATZ, P. 1978. The occurrence of resurrection plants in the Australian flora. Australian Journal of Botany 26: 485-492.

GAFF, D.F. & OLIVER, M. 2013. The evolution of desiccation tolerance in angiosperm plants: A rare yet common phenomenon. Functional Plant Biology 40: 315-328.

GRIFFITHS, C.A., GAFF, D.F. & NEALE, A.D. 2014. Drying without senescence in resurrection plants. Frontiers in Plant Science 5: 1-18.

HALLAM, N.D.1976. Anhydrous fixation of dry plant tissue using non-aqueous fixatives. Journal of Microscopy 106: 337-342.

HALLAM, N. & GAFF, D. 1978. Regeneration of chloroplast structure in *Talbotia elegans*: A desiccation-tolerant plant. New Phytologist 81: 657-662.

HETHZERINGTON, S. & SMILLIE, R. 1982. Humidity-sensitive degreening and regreening of leaves of *Borya nitida* Labill. As followed by changes in chlorophyll fluorescence. Functional Plant Biology 9: 587-599.

HOEKSTRA, F.A., GOLOVINA, E.A. & BUITINK, J. 2001. Mechanisms of plant desiccation tolerance. Trends in Plant Science 6: 431-438.

HUNTER, J.T. 2003. Persistence on inselbergs: the role of obligate seeders and resprouters. Journal of Biogeography 30: 497-510.

HUNTER, J.T. & CLARKE, P.J. 1998. The vegetation of granitic outcrop communities on the New England batholith of eastern Australia. Cunninghamia 5: 547-618.

ITURRIAGA, G., GAFF, D. & ZENTELLA, R. 2000. New desiccation-tolerant plants, including a grass, in the central highlands of Mexico, accumulate trehalose. Australian Journal of Botany 48: 153-158.

JOCQUÉ, M., TIMMS, B. & BRENDONCK, L. 2007. A contribution on the biodiversity and conservation of the freshwater fauna of rocky outcrops in the central wheatbelt of Western Australia. Journal of the Royal Society of Western Australia 90: 137-142.

JUST, K. & EVANS, N. 2010. Discovery of a large population of rye beetle grass '*Tripogon loliiformis*' on the volcanic plains west of Melbourne, with observations on ecology and propagation. The Victorian Naturalist 127: 208.

KEEVER, C., OOSTING, H.J. & ANDERSON, L.E. 1951. Plant succession on exposed granite of rocky face mountain, Alexander County, North Carolina. Bulletin of the Torrey Botanical Club 78 (5): 401-421.

LARSON, D. 2001. Inselberg biodiversity. Ecology 82 (8): 2374-2375.

LE, T.N., BLOMSTEDT, C. K., KUANG, J., TENLEN, J., GAFF, D. F., HAMILL, J. D., NEALE, A. D. 2007. Desiccation-tolerance specific gene expression in leaf tissue of the resurrection plant *Sporobolus stapfianus*. Functional Plant Biology 34: 589–600.

LIAN-BING, C. 2005. *Tripogon debilis* (Poaceae), a new species from western China. Novon 15: 390-392.

LOW, B.S., BIRK, E., LENDON, S. & LOW, W.A.

1973. Community utilization by cattle and kangaroos in mulga near Alice Springs, NT. Tropical Grasslands 7: 149.

MICHAEL, D.R., CUNNINGHAM, R.B. & LINDENMAYER, D.B. 2008. A forgotten habitat? Granite inselbergs conserve reptile diversity in fragmented agricultural landscapes. Journal of Applied Ecology 45: 1742-1752.

MCGANN, T.D., KINGSWOOD, R. & BELL, D. 2001. Vegetation of Narran Lake Nature Reserve, Northwestern Plains, New South Wales. Cunninghamia 7: 43-63.

NEWMASTER, S.G. & RAGUPATHY, S. 2010. Ethnobotany genomics-discovery and innovation in a new era of exploratory research. Journal of Ethnobiology and Ethnomedicine 6: 1-11.

OLIVER, M.J., ZOLTÁN, T. & MISHLER, B.D. 2000. The evolution of vegetative desiccation tolerance in land plants. Plant Ecology 15: 85-100.

OLSEN, M. 1983. Aspects of drought tolerance (with particular reference to the Queensland flora). Honours Thesis. (The University of Queensland).

PALMER, J. & WEILLER, C. 2005. *Tripogon*. Pp. 422-423. In Orchard, A.E. & Wilson A.J.G. (eds), Flora of Australia. (CSIRO Canberra).

PHILLIPS, S. & LAUNERT, E. 1971. A revision of the African species of *Tripogon* Roem. & Schult. Kew Bulletin 25: 301-322.

PHILLIPS, S.M. & CHEN, S.-L. 2002. The genus *Tripogon* (Poaceae) in China. Kew Bulletin 57 (4): 911-924.

POREMBSKI, S. & BARTHLOTT, W. 2000. Granitic and gneissic outcrops (inselbergs) as centers of diversity for desiccation-tolerant vascular plants. Plant Ecology 151: 19-28.

POREMBSKI, S. 2007. Tropical inselbergs: Habitat types, adaptive strategies and diversity patterns. Brazilian Journal of Botany 30: 579-586.

POTDAR, G.G., SALUNKHE, C.B. & YADAV, S.R. 2012. Grasses of Maharashtra. (Shivaji University Maharashtra).

PRENDERGAST, H., HATTERSLEY, P. & STONE, N. 1987. New structural/biochemical associations in leaf blades of C_4 grasses (Poaceae). Functional Plant Biology 14: 403-420.

RAGUPATHY, S., NEWMASTER, S.G., MURUGESAN, M. & BALASUBRAMANIAM, V. 2009. DNA barcoding discriminates a new cryptic grass species revealed in an ethnobotany study by the hill tribes of the Western Ghats in southern India. Molecular Ecology Resources 9: 164-171.

ROBERTS, B.R. 1978. Ecological studies on pasture condition in semi-arid Queensland. (Queensland Department of Primary Industries).

ROGERS, R. & STRIDE, C. 1997. Distribution of grass species and attributes of grasses near a bore drain in a grazed semi-arid subtropical grassland. Australian Journal of Botany 45: 919-927.

RÚGOLO DE AGRASAR, Z.E. & VEGA, A.S. 2004. *Tripogon nicorae*, a new species and synopsis of *Tripogon* (Poaceae: Chloridoideae) in America. Systematic Botany 29: 874-882.

SIMON, B.K. & ALFONSO, Y. 2011. *Tripogon*. In AusGrass2 Available at http://ausgrass2.myspecies.info/ [verified July 2014].

SIMON, B.K., CLAYTON, W.D., HARMAN, K.T., VORONTSOVA, M.S., BRAKE, I, HEALY, D. & ALFONSO, Y. 2011. *Tripogon*. In GrassWorld Available at http://grassworld.myspecies.info/ [verified July 2014].

The Plant List. 2015. *Tripogon*. In The Plant List Version 1.1 Available at http://www.theplantlist.org/ [verified 21 June 2015].

TUBA, Z., PROTOR, C. & CSINTALAN, Z. 1998. Ecophysiological responses of homoiochlorophyllous and poikilochlorophyllous desiccation-tolerant plants: A comparison and an ecological perspective. Plant Growth Regulation 24: 211-217.

UNO, G.E. & COLLINS, S.L. 1987. Primary succession on granite outcrops in southwestern Oklahoma. Bulletin of the Torrey Botanical Club 114: 387-392.

VAN DEN BORRE, A. & WATSON, L. 1997. On the classification of the Chloridoideae (Poaceae). Australian Systematic Botany 10: 491-531.

VICRÉ, M., FARRANT, J. & DRIOUICH, A. 2004. Insights into the cellular mechanisms of desiccation tolerance among angiosperm resurrection plant species. Plant, Cell & Environment 27: 1329-1340.

WANG, Z., A. HOPKINS, AND R. MIAN. 2001. Forage and turf grass biotechnology. Critical Reviews in Plant Sciences 20: 573-619.

WATSON, L. & DALLWITZ, M. 1992 onwards. *Tripogon*. In The grass genera of the world Version 11. Available at http://delta-intkey.com [verified 11 July 2014].

WILLIGEN, C. V., PAMMENTER, N. W., JAFFER, M. A., MUNDREE, S. G. & FARRANT, J. M. 2003. An ultrastructural study using anhydrous fixation of *Eragrostis nindensis*, a resurrection grass with both desiccation-tolerant and -sensitive tissues. Functional Plant Biology

30: 281-290.

WOOD, J. & GAFF, D. 1989. Salinity studies with drought-resistant species of *Sporobolus*. Oecologia 78: 559-564.

YANG, X. 1983. New taxa of *Tripogon* and *Aeluropus* [*Tripogon humilis*, *Aeluropus littoralis*, from Tsinghau, Tibet]. Yun nan chih wu yen chiu: Acta Botanica Yunnanica 5: 1-3.

YOUNG, T.P. & AUGSPURGER, C. K. 1991. Ecology and evolution of long-lived semelparous plants. Trends in Ecology and Evolution TREE 6: 285-289.

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TWENTY TWO YEARS OF INLAND AQUATIC SCIENCE (1993 TO 2015) AND ITS APPLICATION IN QUEENSLAND: ACHIEVEMENTS, LEARNINGS AND WAY FORWARD

CHOY, S.C.

This paper reviews the last twenty two years (1993 to 2015) of inland aquatic science and its application in Queensland and assesses the achievements and learnings, and then proposes a way forward for the future. Many science initiatives and programs have come and gone with various degrees of success. Currently, there seems to be a strong focus on short-term, operational needs. There is very limited investment and capability in long-term strategic research, particularly to address recurring and emerging issues. The preferred way forward would be a mixture of partnership approaches underpinned by a strategic science plan and long term funding. The effectiveness of such research and partnership models should regularly be assessed for their cost and benefit.

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INTRODUCTION

The aim of this paper is to summarize and provide commentary on the past twenty-two years of inland aquatic science in Queensland. Whilst some significant freshwater fish and local-scale ecological studies were carried out in Queensland prior to 1993 (e.g. Arthington et al., 1983; 1992; Arthington & Pusey, 1993; Pollard, 1990) it was not until the National River Health Program (NRHP) was initiated in 1994 that a concerted effort went into establishing State-wide inland aquatic science capability by the Queensland Government and other research institutions. The NRHP was instigated in response to the 1000km long blue green algal bloom in the Murray Darling Basin during the summer of 1991-1992. The objective of the NRHP was to improve the management of Australia's rivers and floodplains for their long-term health and ecological sustainability (Choy & Thompson, 1996). This program triggered not only nationally consistent monitoring and modelling but also a range of research and development programs (Choy et al., 2002a). Whilst the Queensland Government focussed on the development and implementation of a broad scale monitoring and assessment program using standardised methods for macroinvertebrates (Choy & Alexander, 1996; Choy et al., 2002b), academic institutions such as James Cook University and Griffith University investigated the suitability and protocols for a range of other indicators such as fish and algae (Arthington et al., 1998a; Pearson & Connolly, 1998). Strong partnerships and collaborations were developed through Federal and State government funding and co-ordination by the Land and Water Resources Research and Development Corporation (LWRRDC). This included community-based educational and citizen science programs such as Waterwatch.

In 1994, the Queensland Government also embarked on the Water Allocation and Management Program (WAMP) which was later renamed Water Resource Planning (WRP). The environmental water allocation (i.e. water to be left in the waterways for the benefit of biodiversity, ecology, ecosystem services, etc.) had to be underpinned by science and this triggered a range of research projects into the environmental flow requirements of water-dependent ecosystems and species, and methods for determining environmental water allocations (Arthington et al., 1998b). Part of the fund from the NRHP was also allocated to research into environmental flows and then Land and Water Australia (LWA), successor to LWRRDC, had a dedicated program from 2001 to 2009 on environmental water allocation (Sinclair Knight Merz, 2007).

RESEARCH ORGANISATIONS 1993 TO 2015

Prior to 1994 very little aquatic science was carried out by the Queensland Government agencies (Cook, 2012). The main activities were in stream gauging and physical-chemical water quality monitoring for "beneficial use" purposes and in fisheries/aquaculture. Of the universities, the main research centre was the Centre for Catchment and In-stream Research (CCISR) which carried out a number of

significant studies, especially in coastal wetlands and dune lakes (e.g. Arthington et al., 1992). With the establishment of initiatives such as the NRHP and the Integrated Catchment Management programs many other organisations started developing aquatic science programs. These included the Co-operative Research Centres, CSIRO, University of Queensland, James Cook University and University of Central Queensland. CCISR morphed into the Australian Rivers Institute (ARI). Some foundation publications in the early nineties also triggered more concerted efforts in aquatic science. These publications included: "Overview of water resources and related issues" (DPI, 1992), "The condition of river catchments in Queensland: a broad overview of catchment management issues" (DPI, 1993a), "A Guide to ICM in Queensland" (DPI, 1993b), "State Water Conservation Strategy" (DPI, 1993c) and Arthington & Pusey (1993). Perhaps the biggest demise was the shutting down of Land and Water Australia which had emphasised the link between water and the broader landscape and coordinated the National Action Plan on Salinity and Water Quality. The Council of Australian Governments (COAG) water reform was then implemented through the National Water Initiative (NWI) by the National Water Commission (NWC) but, because its emphasis was on the water planning framework to inform water allocation, the integrated landscape-water approach was somewhat lost. Similarly, many specialised centres soon formed, all with somewhat narrow focus (e.g. Advanced Water Centre and Sustainable Minerals Institute at UQ). Interestingly, community-driven partnerships have become a driving force now and their focus is broader, more integrated and driven by sustainability considerations (e.g. Natural Resource Management bodies).

A recent audit of science capability in water within the Queensland Government indicated that water science activities were very operational in nature and primarily driven by short-term needs of sponsoring departments and agencies (Greenfield &Riches, 2014). There was very limited investment and only limited capability in longer-term strategic research on water-related science and technology issues. This contrasted with the thirty-year horizon taken in 2014 in developing a water plan (WaterQ) for the State (Greenfield & Riches, 2014). In 2012, for the first time in the State Government's history, the incoming government established the Department of Science, Information Technology, Innovations and the Arts (DSITIA) as the science (including water science) provider to the other agencies. This model differed from the past approach where relevant science capability was co-located in the same agency as the related policy, management or regulation functions. This mode of delivery has more disadvantages (e.g. misalignment, perceived irrelevance, short-term and reactionary focus, scale, culture, inflexibility, reliance on external funding and sensitivity to short-term changes in funding) than advantages (e.g. longer-term strategic and proactive focus, and perceived independence).

ISSUES THEN AND NOW (1993 TO 2015)

In 1993, a study by the Department of Primary Industries identified the aquatic ecosystem-related issues of highest levels of concern in Queensland. They were erosion, exotic weeds, agro-chemicals, groundwater quality, environmental flows and barriers to fish migration in the Qld Murray Darling Basin (QMDB); exotic weeds in the Lake Eyre-Bulloo; erosion, soil salinity, exotic weeds, urban expansion, groundwater quality, riparian vegetation loss, in-stream habitat loss and barriers to fish migration in Southern Coastal regions; exotic weeds, urban flooding, channel instability, environmental flows and barriers to fish migration in the Central Coast; exotic weeds, environmental flows and channel instability in the Northern Coastal region; and exotic weeds in the Gulf of Carpentaria (DPI, 1993a). Exotic weeds were of high concern in all six regions, followed by environmental flows and barriers to fish migration being of high concern in three of the six regions and then followed by erosion and groundwater quality being of high concern in two of the six regions. Catchments within each region differed in the level of concern and, as expected, the highly populated and urbanised Southern Coastal region (i.e. SE Queensland) had the highest number of issues of high concern (eight out of nineteen). Regions that had the lowest number of issues of high concern were the Lake Eyre Basin and the Gulf of Carpentaria.
A survey of riparian landholders in 1996 identified weed infestation, erosion of top soil and high chemical and nutrient levels as being the high priority issues (DNR, 1996).

In 2001, the loss of riparian habitat was identified as a major concern in all the regions while in 1993 this was perceived as being of very low to moderate concern across all regions except Southern Coastal (TABLE 1 and Choy et al., 2002a). Loss of riparian vegetation is still a major concern now, especially in urban and

TABLE 1. Major changes in priority issues from 1993 to 2001, grouped by themes (from Choy et al., 2002a).

Theme	Southern Coastal		Central Coastal		Northern Coastal		Gulf Carpentaria		Lake Eyre-Bulloo		Murray Darling	
	1993	2001	1993	2001	1993	2001	1993	2001	1993	2001	1993	2001
Natural habitat loss	M-H	H	L-M	H	L-M	H	L-M	H	L	H	M	H
Exotic aquatic weeds	M-H	M-H	M-H	M-H	M-H	M-H	L-M	M-H	M-H	M-H	H	M-H
Surface water availability	M	M	L	L	VL	VH	VL	VH	VL	VH	L	VH
Nutrient enrichment	M	H	L-M	H	L	H	VL	L	VL	L	M	H
Surface water salinity	M	M	VL	M	VL	M	VL	L	VL	M	VL	H
Soil salinity	M-H	L	L	M	VL	M	L	L	L	M	L	H
Sediment load/ turbidity	M	M-H	M	M-H	L	H	M	M-H	M	M-H	M	M-H
Agrochemical pollution	L-H	M	L	H	L	H	VL	L	VL	L	H	M

VL – very low, L – low, M – moderate, H – high, VH – very high

agricultural areas. Surface water availability in the Northern Coastal, Carpentaria, Lake Eyre Basin and the Qld Murray-Darling Basin were rated very low to low in 1993 but in 2001 and now it is a medium to high priority issue (TABLES 1 and 2). New agricultural and mining activities are the cause for this concern. Concern over sediment loads, nutrient enrichment and agro-chemical pollution has increased in the coastal regions, especially in the Great Barrier Reef region. It is interesting to note that in the Murray-Darling system, salinity rated very low in 1993, increased to high priority in 2001 (TABLE 1) and is again a low issue now (TABLE 2). It could be that it is awareness that has changed, not necessarily the salinization. Some issues such as Coal Seam Gas (CSG) and other mining activities as well as Groundwater Dependent Ecosystems, not identified as being of concern earlier are now featured (TABLE 2).

A comparison of 1993 and 2001 data highlights the shift in priority issues throughout the State during that decade. Several issues considered to be of relatively low concern in 1993 had become of high concern in 2001. Clearly, the problems of the loss of riparian vegetation, increasing salinity, fertiliser and pesticide runoff, erosion and sediment loads, and surface water availability had increased in importance. Choy et al. (2002a) suggested that a possible reason for this could have been a result of wider community awareness of issues relating to aquatic ecosystem health following the establishment of the community based Waterwatch program in 1993, the National River Health Program in 1994, the National Heritage Trust programs and the growing number of community based NRM groups in Queensland. The fact that most concerns are still current indicates that it was not just increased community awareness but issues being real problems.

Current issues and priorities seem to be more specifically regionally based. These include the Great Barrier Reef (sediment and nutrient loads), the Gladstone Harbour (dredging and fish diseases), the Moreton Bay (sediment and nutrient loads), the Murray Darling Basin (environmental flows) and northern Australia (agricultural development). Some issues may be more widespread (e.g. CSG and other mining). Monitoring programs based on the Pressure-Stressor-Response framework, such as the Stream and Estuarine Assessment Program (SEAP) and Q-catchments have identified issues such as introduced riparian and aquatic flora and fauna, and deposited sediments (DSITIA, 2012). In the earlier parts of the past 20 years, drought was a prominent feature but since the 2011 floods in SEQ focus has been on impacts of flooding (although currently about 80% of the State is in drought again).

Looking back at the past 22 years, some things have changed for the better and others have not; we

TABLE 2. Major changes in priority issues from 1993 to 2014, grouped by themes.

Theme	Southern Coastal		Central Coastal		Northern Coastal		Gulf		Lake Eyre		Murray Darling	
	1993	2014	1993	2014	1993	2014	1993	2014	1993	2014	1993	2014
Natural habitat loss	M-H	M-H	L-M	M	L-M	M-H	L-M	M	L	L	M	M
Exotic aquatic weeds	M-H	M-H	M-H	L-M	M-H	M-H	L-H	L	M-H	L	H	M
Surface water availability	M	M	L	M	VL	M	VL	M	VL	M	L	H
Nutrient enrichment	M	H	L-M	H	L	H	VL	M	VL	L	M	M
Surface water quality	L	H	VL	H	VL	H	VL	L	VL	M	VL	M
Soil salinity	M	L	L	M	VL	L	L	M	L	L	L	L
Sediment load	M	H	M	H	L	H	M	M	M	M	M	M
Chemical pollution	L	H	M	H	L	H	VL	L	L	M	H	L
Mining and CSG	L	L	L	H	L	M	L	M	L	H	L	H
Groundwater dependent ecosystems	L	H	L	M	L	H	L	M	L	H	L	H

VL – very low, L – low, M – moderate, H – high, VH – very high

now still recognise the importance of a whole-of-catchment approach but we seem to have moved away from "integrated" management and into silos. So whilst some high level planning is done (e.g. regional and city planning), we are no longer integrating our statutory water planning and management with land, weeds, biodiversity conservation, etc. It seems that a critical point of change occurred when legislation for integrated resource planning was abandoned and it was decided to pursue reform through individual sectoral legislation such as the Water Act 2000. A 10-year vision for "Sustainable Water Management" of the DNR Science Plan 1999-2008 was "fully integrated management of surface water, groundwater and the land and vegetation resources at catchment scale" (DNR 1999). This vision has not been achieved. Some issues are still there, others have changed and some issues not flagged then are now high on the agenda (e.g. agricultural expansion in northern Australia, CSG and other mining activities). Demand for more effective database and modelling is still there and the recent open data initiative by the State Government provides exciting prospects. Investment in information technology and databases now allow easier data capture and access. Many national initiatives have come and gone with varying success (e.g. Natural Heritage Trust, Co-operative Research Centres, National Land and Water Resources Audit, National Action Plan on Salinity and Water Quality, National Water Initiative) and new ones initiated (e.g. Reef Plan, SEQ and Gladstone Harbour Healthy Waterways, LEB Forum, National Environmental Research Program, Queensland Plan, WaterQ, ResourcesQ, etc.). Water planning has primarily focussed on the provision of flows with much less consideration of other confounding and impacting factors such as water quality, exotic species, riparian condition, etc. Even the Murray Darling Basin Plan has this focus. A more integrated model for planning and management that takes into consideration other land, vegetation and water factors and, is underpinned by multi-disciplinary science, is required to better achieve ecological outcomes.

ACHIEVEMENTS AND LESSONS

The Moreton Bay Partnership (MBWCP) has morphed into SEQ Healthy Waterways and, whilst there are some policy and management issues, is still going strong. It has been underpinned by good science (Bunn et al., 2010) and the same can be said of the LEB Forum. The message is that strong partnerships underpinned by good science last for a long time. Choy et al. (2002a) recommended that such a model be considered for other regions and this seems to have been heeded. We now have

Gladstone, Fitzroy, Reef, Murray Darling Basin and Lake Eyre Basin partnerships. There is a case to establish similar partnerships in the Gulf and Cape York regions but overheads will need to be considered. Using existing NRM bodies may be an effective way to get these going.

So, has aquatic science made any difference to the sustainable management and condition of aquatic ecosystems in Queensland? There are several cases that strongly suggest that yes, it has made a positive difference. For example, the strong scientific basis of the Water Resource Plans clearly identifies the ecological outcomes to be achieved from environmental water allocations. Reviews of the Water Resource Plans that have been implemented indicate that the outcomes are being met and negative impacts have been avoided. Results from ecological monitoring programs suggest that some urban streams such as Enoggera Creek and Bulimba Creek have actually improved in condition, at least in some of the reaches. Point source pollution has been effectively tackled in Southeast Queensland but the challenges of diffused sources remain. It could also be argued that science-based knowledge and communication have averted or slowed down aquatic environmental degradation (e.g. in the Lake Eyre Basin) and triggered rehabilitation (e.g. in the GBR and the Murray Darling Basin).

The scientific research and condition assessments have increased stakeholder and community awareness as well as having helped in articulating aquatic ecosystem services and values. These have resulted in strong advocacy for the conservation of waterways that are in good condition (e.g. the Lake Eyre Basin) and the improvement of those that are not (e.g. tributaries of the Brisbane River, Gladstone Harbour and the Qld Murray Darling Basin). Recent assessments suggest that of the 75 drainage basins in Queensland about 50 (or 67%) are in relatively good condition. The rest are in moderate condition with only a few in poor condition. Queenslanders and indeed, all Australians are more aware that prevention of problems is much better than trying to fix the problems after they have occurred.

LOOKING FORWARD FROM 2015

The capability of aquatic science in Queensland is quite strong, both within the Queensland Government and outside it. Over the past 20 years, resourcing and capability in aquatic science have fluctuated over time and the focus on the key Government responsibilities and activities within surface water, ground water and aquatic ecosystems have changed periodically. However, activities are now very operational in nature, being primarily driven by the short term needs of sponsoring departments and agencies (Greenfield & Riches, 2014).There is very limited investment and capability in longer term strategic research, particularly to address recurring (such as droughts and floods) and emerging issues. This contrasts with the state's thirty year planning horizon taken in developing water plans, the Queensland Plan, WaterQ, ResourcesQ, etc., as well as climate change. In the past, national initiatives and funding have triggered complementary medium-term state programs (e.g. NRHP, NAPSWQ, MDBP) but recently even the national direction has been lacking. The current National Water Knowledge and Research Platform (NWKRP) does not have any associated delivery strategy or funding. Even external research institutions (eg. CSIRO, ARI (Griffith Uni), Advanced Water Management Centre (UQ) and TropWATER (JCU) all have a strong "applied" focus rather than a longer term focus on more fundamental science. This has largely been driven by the requirements of the funding agencies such as the Federal Government and the Australian Research Council, which has also led to some competition amongst the science providers.

The preferred way forward would be a combination of partnership approaches underpinned by a strategic science plan and long term funding. The NWKRP could form a good starting point for a science plan. The Cooperative Research Centres (CRCs) and the National Environmental Research Program (NERP) hubs provide opportunities for some science delivery as do broader stakeholder partnerships such as the SEQ Healthy Waterways and the LEB Forum. The effectiveness of such research and partnership models should regularly be reviewed and assessed for their cost and benefit.

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LITERATURE CITED

ARTHINGTON, A.H., MCKAY, R.J. & MILTON, D.A. 1983. Effects of urban development and habitat alteration on the distribution and abundance of native and exotic fish in the Brisbane Region, Queensland. Australian Journal of Ecology 8: 87-101.

ARTHINGTON , A.H., CONRICK, D.L. & BYCROFT, B.M. 1992. Environmental study of Barker-Barambah Creek. Centre for Catchment and In-stream Research, Griffith University, Brisbane.

ARTHINGTON, A.H. & PUSEY, B.J. 1993. In-stream flow management in Australia: methods, deficiencies and future directions. Australian Biologist 6: 52-60.

ARTHINGTON, A.H., KENNARD, M.J. & MACKAY, S.J.1998a. River Bioassessment using Fish Community Structure. Final Report on National River Health Program Project GRU 19, National River Health Program, LWRRDC, Canberra.

ARTHINGTON, A.H., BRIZGA, S.O. & KENNARD, M.J. 1998b. Comparative Evaluation of Environmental Flow Assessment Techniques: Best Practice Framework. LWRRDC Occasional Paper 25/98. National River Health Program, LWRRDC, Canberra.

BUNN, S.E., ABAL, E.G., SMITH, M.J., CHOY, S.C., FELLOWS, C.S., HARCH, B.D., KENNARD, M.J. & SHELDON, F. 2010. Integration of science and monitoring of river ecosystem health to guide investments in catchment protection and rehabilitation. Freshwater Biology 55 (Suppl. 1): 223-240.

CHOY, S.C. & ALEXANDER, D. 1996. What's bugging Queensland Hydrographers? Australian Hydrographer 4 (3): 26-31.

CHOY, S.C., RAMAGE, D., JONES, G. & BARRATT, P. 2002a. Prioritising research on inland aquatic ecosystems in Queensland. Consortium for Integrated Resource Management and Department of Natural Resources and Mines, Queensland.

CHOY, S.C. & THOMPSON, C.B. & MARSHALL, J.C. 2002b. Ecological Condition of Central Australian arid-zone rivers. Water Science and Technology 45(11): 225-232.

CHOY, S.C. & THOMPSON, P. 1996. River Bioassessment and monitoring using benthic macroinvertebrate community structure: the Monitoring River Heath initiative. Pp. 53-55. In Hunter, H.M., Eyles, A.G. & Rayment, G.E.(eds), Downstream effects of Landuse. (Department of Natural Resources, Brisbane).

COOK, M. 2012. Serving Queensland through Science. A History of the Indooroopilly Sciences Centre, 1960-2010. Water. Pp. 167-179. Queensland Government, Brisbane.

DNR. 1996. Managing Queensland's Rivers: a rural landholder survey. Department of Natural Resources. The State of Queensland.

DNR. 1999. DNR Science Plan 1999-2008. Department of Natural Resources. The State of Queensland.

DPI. 1992. Overview of water resources and related issues. The Curtis Region. Queensland Government, Brisbane.

DPI. 1993a. The condition of river catchments in Queensland: a broad overview of catchment management issues. Department of Primary Industries, Brisbane.

DPI. 1993b. A guide to ICM in Queensland. Department of Primary Industries, Brisbane.

DPI. 1993c. State water conservation strategy. A discussion paper. Department of Primary Industries, Brisbane.

DSITIA. 2012. The Warrego Catchment: Condition of Riverine Ecosystems. Summary Report. Q-catchments Program. The State of Queensland;Department of Science, Information Technology, Innovation and the Arts, Queensland, Australia

GREENFIELD, P. & RICHES, J. 2014. Science capability audit: water. Office of the Queensland Chief Scientist, Queensland Government, Brisbane.

PEARSON, R. & CONNOLLY, N. 1998. Macroinvertebrates as monitors of River Health in the Tropics. Final Report on National River Health Program Project JCU 11, National River Health Program, LWRRDC, Canberra.

POLLARD, D.A (Ed.). 1990. Introduced and translocated fishes and their ecological effects. Proceedings of the Australian Society for Fish Biology, Workshop No. 8. Bureau of Rural Resources, Aust. Govt., Canberra.

SINCLAIR KNIGHT MERZ. 2007. Knowledge needs for the Environmental Water Allocation R&D Program Final report. Land & Water Australia, Canberra.

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POLITICS, FINANCE AND TRANSPORT – MEGAPROJECTS IN AUSTRALIA

ELAURANT, S.[1] & LOUISE, J.[2]

This paper reviews the funding and delivery of transport infrastructure projects in Australia at the macro- and micro-(project) level. At the macro-level it identifies that Australia's transport infrastructure is rated low in international comparisons, despite funding levels that have varied from average to high. At the micro-(project) level the paper examines a sample of Australian projects to test whether cost and demand risks have been well controlled. It finds that overall cost risks have been well controlled, with lower cost overruns than other OECD countries. Demand risks have been poorly controlled for public private partnership (PPP) projects, which have greater forecasting errors than other projects by a significant margin. In conclusion reforms are proposed for the decision making, assessment and delivery processes for transport projects to increase transparency, independence and consistency. A statutory national infrastructure body with decision making powers is recommended.

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INTRODUCTION

In Australia the past decade has seen the delivery of multiple transport megaprojects costing over a billion dollars each. However the success in delivery has been mixed. Four of the last six toll-road tunnels built in Australia, costing over ten billion dollars, have become bankrupt or suffered major capital loss within three years of opening. They also failed to deliver their stated transport objectives, in terms of patronage, and would have had benefit – cost ratios of less than one, making the decision to build them highly questionable. A 67% failure rate in a category of investment suggests a systemic flaw in decision making.

This paper considers major road and rail projects built in Australia in the period 1990 to 2014. It examines trends in project unit cost, delivery risk and demand risk, following a similar methodology to Flyvbjerg (2003). It also considers public private partnerships (PPPs), these having been a particular source of debate. The trends are used to draw conclusions on the nature of project planning, assessment and delivery. Recommendations are made on the required reforms.

This paper updates and develops the themes in an earlier paper, Politics Funding and Transport, by Elaurant and McDougall (2014). The 2014 paper reviewed trends in transport infrastructure funding and delivery in Australia since 2000. Following the 2014 paper, I take it as a given that the infrastructure funding and decision making process (i.e. project selection) in Australia has become dysfunctional. The question is not whether reform is needed, but what are the causes of the problems, and what should be done to address them.

TRANSPORT FUNDING – THE MACRO LEVEL

LAND TRANSPORT INFRASTRUCTURE FUNDING 2001 TO 2014

The funding of land transport infrastructure in Australia has been erratic over the past two decades, despite sustained high growth rates in both population and economic activity. Infrastructure funding in Australia had been falling in real terms since the 1980s, as the focus of State and Federal budgets was to reduce debt and manage rising health costs. In the decade up to 2007 road and rail capital funding averaged 0.6% of GDP. This was average by OECD standards, but well below historical norms, and arguably inadequate given Australia's large distances and high growth rate. Funding increased to 1.1% of GDP (higher than OECD average) after the global financial crisis (GFC) (2008-2012), when road and rail projects were included as part of the stimulus package to respond to the GFC. Subsequently in State and Federal budgets transport funding had reduced to below trend again by 2014. Infrastructure funding in real terms from 2003 to 2017 (2013 budget projection) is given in FIG 2.1. This shows government funding, and does not include private capital used for public private partnerships or privately used infrastructure, such as mining railroads.

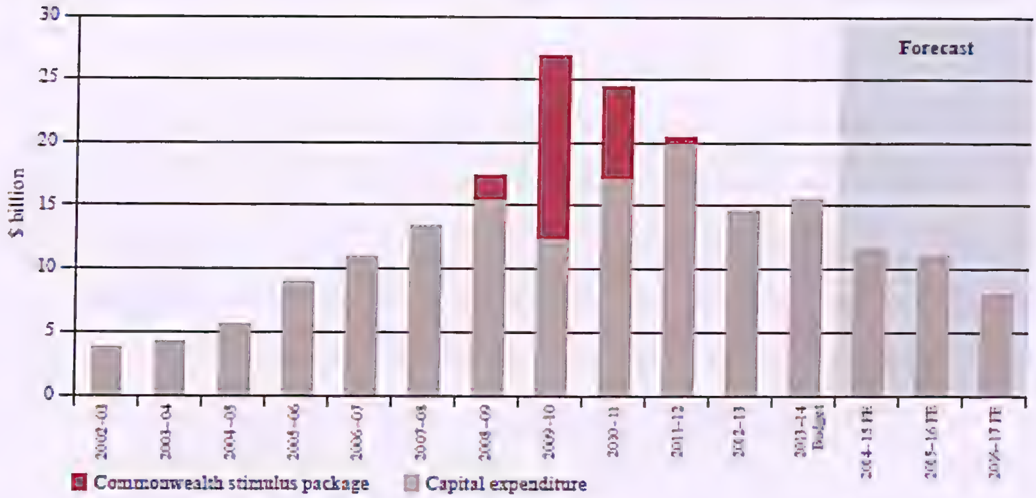

FIG 2.1 Australian infrastructure funding 2003 to 2017 (Infrastructure Australia, 2015)

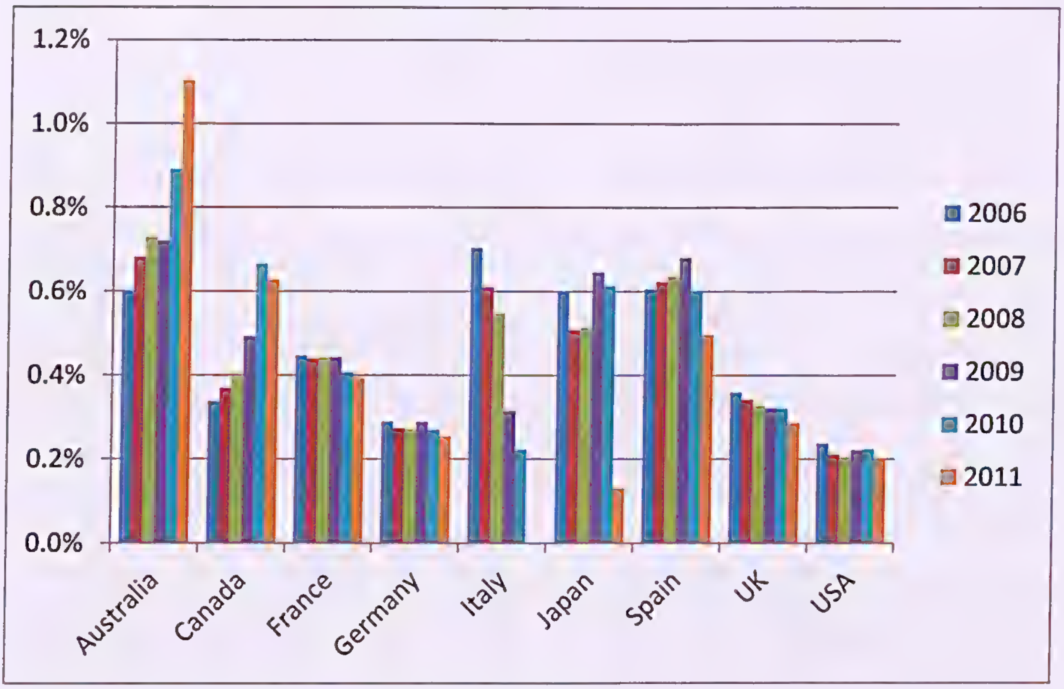

FIG 2.2 Road and Rail Funding as Percentage of GDP (OECD 2015)

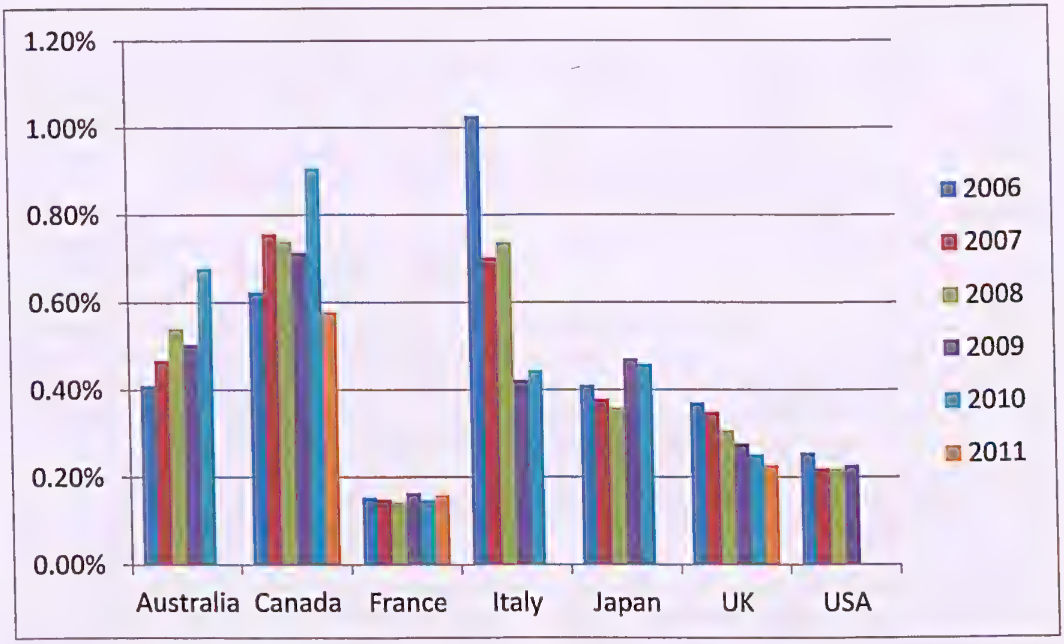

FIG 2.3 Road Maintenance Funding as Percentage of GDP (OECD 2015)

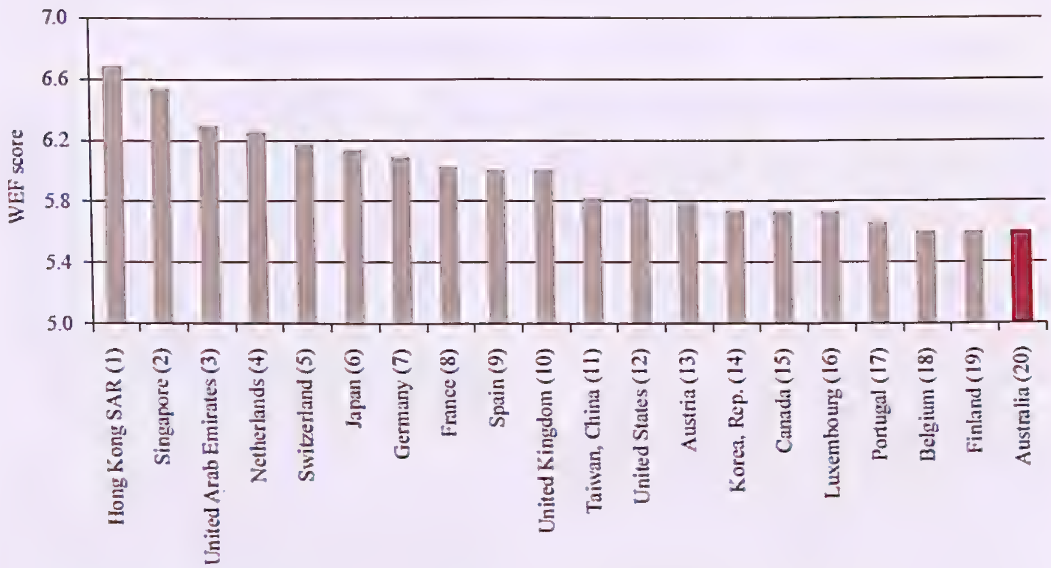

FIG 2.4 Infrastructure Quality Ranking 2014 (World Economic Forum in Infrastructure Australia, 2015)

The comparatively high level of recent capital investment in Australia may be seen by comparisons with other OECD nations that report investment in a similar fashion. Australian transport investment as a percentage of GDP is shown in FIG 2.2, compared with eight other OECD nations. Investment levels dropped in many other countries after the global financial crisis of 2008-09, underlying the significance of the increase in Australian funding.

The other element of infrastructure funding is for maintenance. Here Australia fares more poorly. Despite very long lengths of road and rail networks to maintain, Australia has spent an average of approximately 0.5% of GDP on maintenance. This is barely average by OECD standards, and compares poorly to Canada, another OECD nation of similar size. Road maintenance as a percentage of GDP is shown for OECD nations (where given) in FIG 2.3.

Spending on infrastructure does not necessarily correlate with quality. The World Economic Forum rankings of nations for quality of infrastructure are shown in FIG 2.4. Of the nations in FIG 2.1, Australia had the highest expenditure, and the second lowest rated system quality. In part this is due to Australia's large distances, though note that Canada, has similar distances, lower spending, and yet higher quality infrastructure.

POPULATION AND ECONOMIC GROWTH 2001 TO 2014

Funding and quality of transport infrastructure in Australia needs to be considered in the context of demand, which is driven by growth in population and economic activity. Australia has been one of the fastest growing countries in the OECD in the past decade, with population increasing 1.5% per annum between 2000 and 2010. Only four of the 34 OECD nations grew faster (Department of Infrastructure and Regional Development, 2013). The world population growth rate averaged 1.1% per annum over the same period.

The Australian economy has also been growing faster than the OECD average for the decade since 2001. For the period 2001 to 2013, real GDP growth has averaged 2.6% per annum, well above the OECD average of 1.7% (OECD, 2015).

The population growth is located predominantly in Australia's largest cities. Aside from small city states Australia is the most urbanised country in the OECD, with more than 75% of the population living in cities. Australian major city population growth averaged 1.7% per annum from 2001 to 2011, higher than the national growth rate. Despite talk of "sea-changes" and "tree-changes", the proportion of population living in major cities continues to grow.

Economic production is also centred in our major cities. Aside from the mining industry, the vast majority of Australia's production and services occurs in capital cities, generating 80% of national GDP (Department of Infrastructure and Regional Development, 2013). The capital city share of our economic production per person is greater than average. Cities subsidise rural areas in Australia, not vice versa.

Australia's rate of economic growth has slowed markedly since the end of the mining boom in 2012-13, however the rate of population growth has not. It is forecast to remain high by OECD standards for the foreseeable future. This is due to a combination of a high immigration rate, average demographic profile, and high birth rate. Australia's population will exceed 30 million by 2031, on the ABS medium series projection. Our major cities will grow by another 45%, or almost six million additional residents, in this time (Department of Infrastructure and Regional Development, 2013). . In this respect Australia is part of a world-wide trend towards urbanisation, and this outcome is not caused by government policy. The question is – how do we respond?

AUSTRALIAN INFRASTRUCTURE AUDIT

The state of Australian infrastructure funding and performance was the subject of the Australian Infrastructure Audit Report, by Infrastructure Australia (2015). This reviewed all types of infrastructure, including transport, power communications and water. Common problems were identified in all sectors. Transport, being the largest sector in terms of both cost and economic contribution, was identified as a particular problem. Australian infrastructure now compares poorly within the OECD, even to other countries with large distances such as Canada.

The Audit identified numerous existing and future gaps in transport infrastructure quality and capacity. The combined cost of these gaps is congestion already costing $13 billion per annum (*less* than current capital investment of $15 billion in 2014/15). The cost of transport investment now

exceeds revenue from transport charges (fuel levy, etc). Motorists no longer subsidise other services, but rather motoring and public transport are both subsidised by other tax streams.

A criticism of the report is that demand management was considered only in capacity allocation terms, with no mention of policies such as road pricing, parking restrictions, land use policies or behavioural change. The Audit tends to look at the quantum of future needs and how they might be funded, not whether they can be avoided through a different approach to transport and urban planning. In this regard we should note from FIGS 2.2 and 2.3 that Canada, France and Germany, all have better rated infrastructure, but spend less on transport than Australia in percentage terms. These criticisms aside, the conclusions of the report and calls for reform of transport institutional arrangements are supported.

MACRO LEVEL CONCLUSIONS ON TRANSPORT FUNDING

Infrastructure investment levels in Australia were low prior to 2008/09, especially for a physically large country with high population growth. Infrastructure investment from 2008/09 to 2012/13 was high both by Australian historical and international standards. Investment has dropped back to previous levels since 2013. Against this, population growth in Australia has also been higher than OECD norms, increasing demand. This has resulted in a growing shortfall of funds available against approved projects requiring funding. Maintenance funding, which has remained average to below average throughout, remains deficient.

Other macro-level issues besides funding shortfalls for capital investment exist, but have been given less attention. Alternatives to infrastructure investment, such as demand management, have been only peripherally considered. Transport is a derived demand, and increasing transport investment needs to be seen as a means to an end, and not an end in itself.

The underlying question of whether there should be an attempt to reduce population growth has been barely discussed in infrastructure policy papers. From the viewpoint of welfare of individuals, growth in income per capita is what is of ultimate benefit, not growth per se. Australia has high population growth and a high standard of living. This is rare, and arguably only achievable with a resource advantage. Other countries have achieved high standards of living with lower population growth, notably in northern Europe and Scandinavia. Of the ten highest ranked countries for overall standard of living in 2014, none of the other nine had as high a population growth rate as Australia (United Nations Development Program, 2014).

In the next section we shall ask the question – how well has this money been spent? To do this we shall examine a sample of available evidence – such as it is – for project delivery.

MEGAPROJECTS IN AUSTRALIA

DEFINING MEGAPROJECTS AND DATA IN AUSTRALIA

The previous section identified the macro-economic context of transport infrastructure in Australia in terms of demand growth and variation in funding levels. This chapter examines the delivery performance of a database of road and rail projects in Australia to answer the question, was the money well spent? It will consider two metrics Flyvbjerg (2003) used:

1. Cost overrun, which I will define as cost risk, or delivery risk, and
2. Demand forecasting accuracy, which I will define as demand risk.

To these are added a further metric, the *unit cost* achieved by the project:

3. Unit Cost, measured as real cost per lane- or track-km.

A database has been compiled of 38 Australian major road or rail projects completed between 1990 and 2015, ranging in size from a real 2015 cost of $200 million to $5 billion (2015$). In this context "megaprojects' have been defined as capital values over one billion AUD$. The sample contains 21 megaprojects, including 13 road, 7 rail and one busway. The sample has been extended over a 25 year period to see whether there is any change over time.

A major difficulty in conducting such an analysis in Australia is the lack of publically available data at the project level. No agency publishes all details of planning studies that precede projects. Many of the details that are published are lost over time as Departmental websites are restructured and some information deleted with each change in government. There are few instances in Australia of post-implementation reviews to test whether

TABLE 3.1 Transport Project Database 1990 to 2015

Project	Year Open	Cost ($m)	Real Cost (2015 $m)	Mode	Type	Length (km)	Real Cost/ Lane km $m	Contract Type
Sydney Harbour Tunnel	1992	$554	$1,106	Road	Tunnel	2.8	$99	PPP
M2 Motorway Sydney	1997	$496	$914	Road	Surface	21.4	$11	PPP
Eastern Distributor Sydney	1999	$730	$1,310	Road	Tunnel	6	$55	PPP
City Link Melbourne	2000	$2,200	$3,947	Road	Surface	22	$30	PPP
Sydney Airport Rail	2000	$900	$1,615	Rail	Tunnel	10	$81	PPP
South East Busway Brisbane	2000	$520	$912	Bus	Surface	16.5	$28	Trad
Pacific Motorway SEQ	2000	$850	$1,491	Road	Surface	43	$4	Alliance
Airtrain, Brisbane	2001	$220	$362	Rail	Surface	8.5	$21	PPP
Yelgun Chinderah, NSW	2002	$348	$573	Road	Surface	29	$5	D&C
Alice Springs-Darwin Rail	2004	$1,200	$1,894	Rail	Surface	1420	$1	PPP
Cross City Tunnel, Sydney	2005	$680	$967	Road	Tunnel	2.1	$115	PPP
M7 Motorway, Sydney	2006	$1,800	$2,423	Road	Surface	40	$15	PPP
Regional Fast Rail, Vic	2006	$750	$1,066	Rail	Surface	240	$2	D&C
Perth Mandurah Rail, Perth	2007	$1,660	$2,133	Rail	Surface	70	$15	Trad
Lane Cove Tunnel, Sydney	2007	$1,100	$1,414	Road	Tunnel	3.6	$79	PPP
Liverpool Parramatta T-Way, Sydney	2003	$346	$546	Bus	Surface	30	$9	D&C
Inner Nth. Busway, Brisbane	2008	$493	$614	Bus	Tunnel	4.5	$68	D&C
Tugun Bypass, Gold Coast	2008	$543	$676	Road	Surface	7	$24	D&C
East Link, Melbourne	2008	$2,500	$3,114	Road	Surface	39	$13	PPP
Deer Park Bypass Melbourne	2009	$362	$426	Road	Surface	9.3	$11	D&C
Epping Chatswood, Sydney	2009	$2,350	$3,020	Rail	Tunnel	14	$108	D&C
Forrest Highway, Perth	2009	$705	$829	Road	Surface	70	$3	Alliance
Clem 7 Tunnel, Brisbane	2010	$3,200	$3,493	Road	Tunnel	4.8	$182	PPP
Gateway Upgrade, Brisbane	2010	$1,880	$2,212	Road	Bridge	20	$18	D&C

Project	Year Open	Cost (Sm)	Real Cost (2015 Sm)	Mode	Type	Length (km)	Real Cost/ Lane km Sm	Contract Type
Go Between Bridge Brisbane	2010	$338	$369	Road	Bridge	0.7	$132	PPP
Monash-CityLink-Westgate, Melbourne	2010	$1,390	$1,517	Road	Surface	19.5	$13	Alliance
Northern Expressway, Adelaide	2011	$564	$621	Road	Surface	23	$7	D&C
Airport Link, Brisbane	2012	$4,800	$5,288	Road	Tunnel	6.7	$132	PPP
Western Ring Road,								
Melbourne	2013	$2,250	$2,407	Road	Surface	38	$32	D&C
Peninsula Link, Melbourne	2013	$760	$774	Road	Surface	27	$7	PPP
Butler Rail Extension, Perth	2013	$221	$225	Rail	Surface	7.5	$15	Trad
Ipswich Motorway, Brisbane	2014	$2,800	$2,996	Road	Surface	21	$24	Alliance
Seaford Rail Link Adelaide	2014	$291	$292	Rail	Surface	5.7	$26	D&C
South Road Superway Adelaide	2014	$930	$948	Road	Bridge	4.8	$33	D&C
Gold Coast Light Rail	2014	$949	$953	Lt Rail	Surface	13	$37	PPP
Regional Rail Link Melbourne	2014	$3,650	$3,719	Rail	Surface	47.5	$39	Trad
South West Rail Sydney	2015	$1,800	$1,809	Rail	Surface	11.4	$79	D&C
Legacy Way, Brisbane	2015	$1,500	$1,507	Road	Tunnel	4.6	$82	PPP

'Contract type' refers to the construction contract. These may be either PPP (Public Private Partnership), D&C (Design and Construct), Alliance or Trad. (Traditional = separate design and construction contracts).

project objectives were achieved. Overall Australian practice in the publically accessible reporting of publically funded transport projects is very poor by OECD standards.

Data has been obtained from public sources including State and Federal government agency annual reports, budgets and audit reports, as well as papers by Bain (2009), Martin (2011), and Wood (2010). Data was sought from State transport agencies on project performance, particularly forecast and actual demand levels. Two States replied within the timeframe required for preparing this paper. A list of the transport projects sampled is contained in TABLE 3.1, together with their type and real cost in 2015 dollars.

ANALYSIS

Project data for unit cost, cost risk (final cost versus planned cost), demand risk (actual opening patronage versus planned patronage) has been fitted to a statistical model (See APPENDIX 1 for details). Projects are compared over time by work type (road or rail; surface, bridge or tunnel) and contract type (PPP or other: alliance, D&C or separate contracts).

Unit cost. From this analysis, the first point to make is that the real unit cost of the sampled projects has not varied greatly over time. There is no statistically significant trend of rising unit costs for each project type. The individual trends are similar for both road and rail projects. Recent project costs have been high due to an increasing use of tunnels, which are consistently the most expensive construction type. Unit costs (real cost per lane-km in million 2015$) are shown in FIG 3.1. (Tunnels are shown in red. PPP contracts are shown as solid data points.)

The clearest differentiator of project cost is whether the infrastructure is being constructed on surface, elevated (bridge structure) or in tunnel. Whether a road or rail project, infrastructure elevated on bridge structures ($61m/lane km) costs on average three

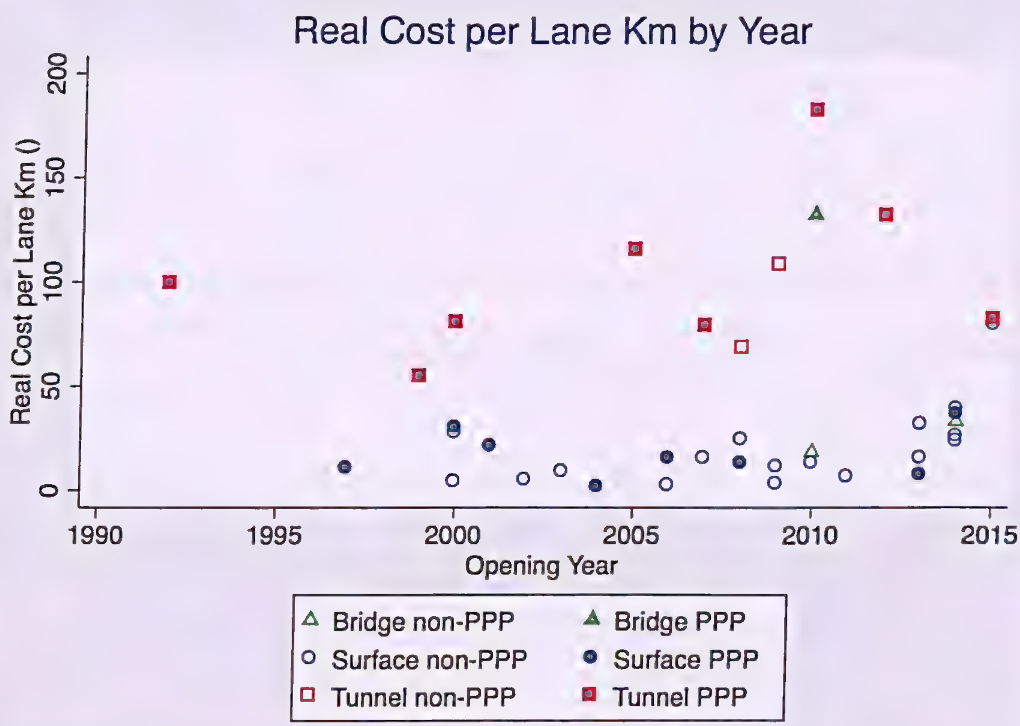

FIG 3.1 Project Unit Costs 1990 to 2015 (Real cost per lane/track km in 2015 $m).

times the cost of surface infrastructure ($21m/lane-km), while tunnels ($102m/lane km) cost on average five times surface infrastructure.

There is little difference between the unit cost per length by mode. The unit capital cost of rail projects in the sample is slightly lower than for road projects. However this is due to the large number of road tunnel projects. Within each type (surface, bridge or tunnel) the difference in average unit cost of road and rail projects is not significant.

A statistical model was fitted to test the effect of contract type (PPP vs non-PPP). The difference between PPP and non-PPP projects within each project type was not statistically significant. The primary driver of high average unit cost in recent PPP projects has been that they were mainly tunnels, not that they were delivered by a PPP contract.

Cost risk. Cost risk has been measured by comparing the final construction cost per lane or track-km with the planned construction cost per lane or track-km, converting both to real 2015$. The results are shown in FIG 3.2. (Tunnel projects are shown in red. PPPs are shown as solid data points.)

There is a marked skewing of cost overrun data by all project types and for each contract type. There are far more cost overruns than cost underruns, with the average project finishing +15% over the original budget in real terms.

Other than the skewing, there is no obvious pattern of cost overrun. The risk of cost overrun was not statistically significant for project size, project type, or contract type. There was a cost risk of approximately 15% whether the project was built on surface, bridge or tunnel, and whether it was delivered as a PPP or public funded. This performance compares well with other countries and studies. Studies have shown typical road and rail project cost overruns of 34% (road) and 45% (rail) (Flyvbjerg, 2003).

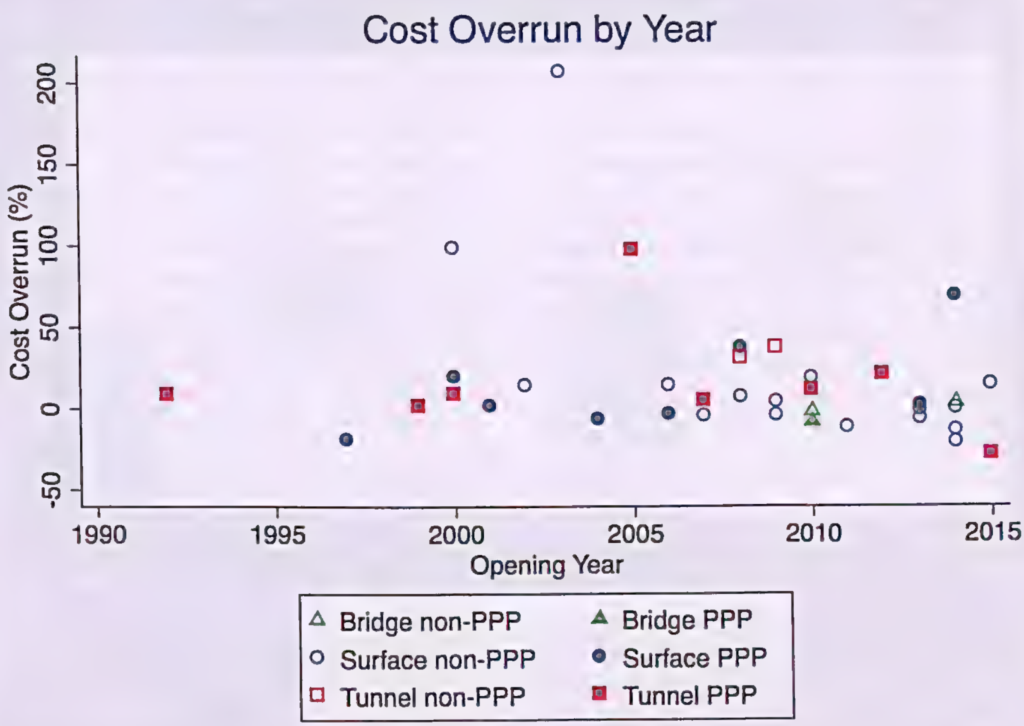

FIG 3.2 Cost Risk by Project Type.

This result is also contrary to Flyvbjerg's European finding that larger projects have higher cost risks than smaller, and that rail projects have higher cost risks than road. Overall, construction cost overruns seem to be better controlled in Australia than in Europe for the reported examples.

Construction time overruns (actual opening date versus planned) were also compared for the project sample. Overall delivery time performance for the sampled projects was very good. Average delivery time performance was -1% compared to scheduled completion, compared to +13% for the international comparator projects. Only two of thirty eight projects were delayed by more than 30% and most projects were completed within 10% of the planned construction period. As many projects finished ahead of schedule as behind, indicating there is no evidence of bias or over-optimism in construction time forecasting. The majority of PPP projects finished ahead of schedule, though the difference was not statistically significant.

Demand risk: Forecasting accuracy. The final aspect of project delivery that we consider is demand risk, or the accuracy of demand forecasts. This is assessed by comparing the percentage difference between the actual patronage using the project and the reported forecast of future demand prepared in the planning stage. Opening patronage was taken as average daily patronage at the end of the first year after opening. A statistical model was fitted to test whether there were any patterns in demand risk by project type and contract type (see APPENDIX 1). Box plots showing the median (%) forecasting error, inter-quartile range and 1.5 times inter-quartile range (from the median) by project type and contract type are shown in FIG 3.3.

Overall average error in demand forecasting was approximately -15%. In this case the error was patterned by contract type to a significant degree. Average forecasting error was 44% greater for PPP projects than non-PPP projects, and consistently

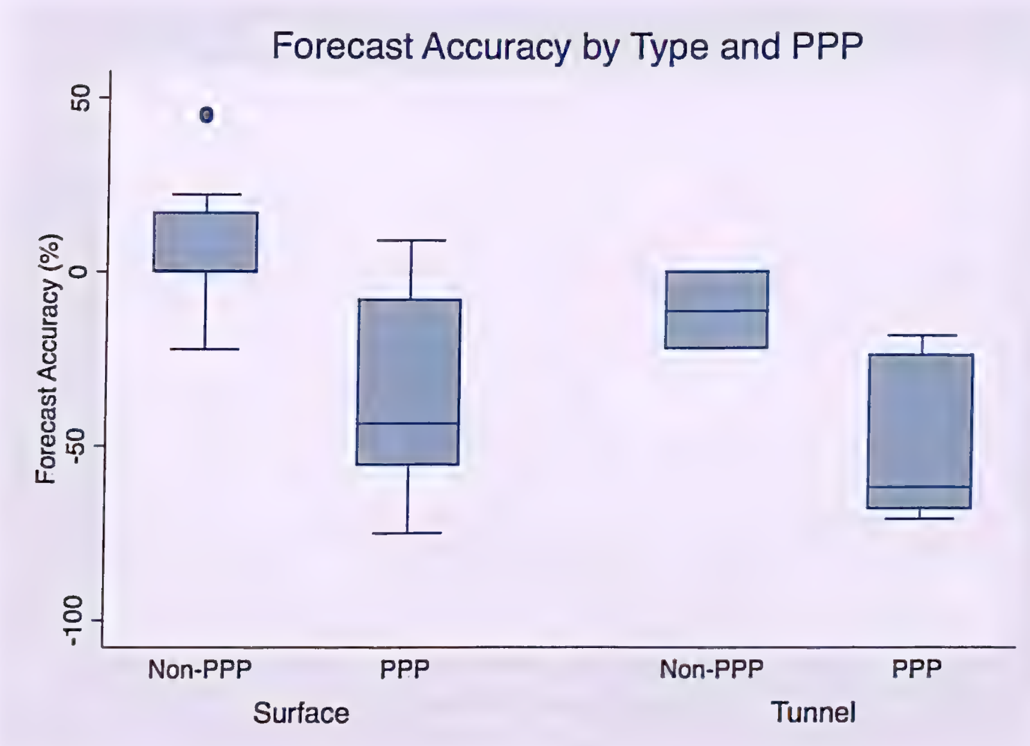

FIG 3.3 Demand Risk by Project Type

skewed (negative). This result was statistically significant for both surface and tunnel projects. That is, PPP projects tended to have greater demand forecast errors whether surface or tunnel. The error for Australian PPPs is comparable to European rail project forecasting errors (-39%) and the Australian non-PPP error is comparable to European road projects (-20%). The median error for PPP tunnels (>-50%) is within the -50% to -70% range identified by Flyvbjerg for European megaprojects.

Demand risk was not obviously patterned over time or by project size or type. Demand risk did not increase with project size whether for PPPs or non-PPPs. The problem of demand forecasting over-estimation for PPP projects has been persistent over time. Likewise PPP demand risk has been an issue with road and rail PPPs (the Sydney Airport Railline and Brisbane Airtrain projects both also failing financially with below forecast demand).

Recent Australian PPP projects. Given that demand risk (forecasting error) for PPP projects has been a persistent problem over time, the question remains why the recent generation of PPP road projects has seen more financial collapses than the earlier generation of PPP projects built in the 1990s? The answer lies in the higher cost and economically more marginal nature of the recent projects. Earlier PPP road projects suffered patronage over-estimation, however being either surface projects with lower costs (City Link, M2, M5 East) or tunnels on high demand routes where drivers were willing to pay a toll premium (Eastern distributor) or demand risk was held by government (Sydney Harbour Tunnel) the projects were still viable. Where this was not the case (Sydney Airport Rail, Brisbane Airtrain) the earlier PPP projects also became bankrupt. The recent PPP toll roads that financially collapsed were all tunnels (Sydney Cross City, Lane Cove, Clem 7 and Airport Link). Melbourne East Link also suffered below forecast patronage, and suffered a capital loss but not bankruptcy. Of recent PPPs, only Go Between Bridge and Gold Coast Light Rail have opened near forecast demand.

The conclusion shows that there were two problems with the failed PPP projects. The first was demand forecasting bias and error. The second was the decision to build the high cost projects themselves. Even if the demand forecasting had been perfect, the actual levels of demand were not sufficient to justify building the scope as delivered. The projects' scope and form should have been reviewed. A PPP contract may assist government in delivering projects for which it does not have funds. However a PPP cannot make unviable projects viable. As the Productivity Commission (2014) noted, PPPs are not "a magic pudding".

This highlights weaknesses in the planning and delivery processes of major projects. Flyvbjerg (2003) saw PPPs as a solution to the problem of cost risk and demand risk in European major projects by introducing market discipline with private capital at risk. Several of Flyvbjerg's recommended governance measures were not present in the failed Australian PPPs. The project contracts were not transparent, with government agencies not independent, acting as promoters as well as regulators. The Australian PPP projects resolved cost risk but not demand risk. In other jurisdictions with different structural approaches to PPPs, including Canada, Chile and USA, PPPs have been successful (Cuttaree, 2008). The technical causes of demand forecasting bias in Australian PPPs have been discussed by Smith (2011). In light of successful examples of PPP mechanisms in other jurisdictions, the structure of Australian PPP contracts should also be considered as a cause of failure.

This lesson appears not to have been learnt. One of the subsequently proposed Australian PPP projects (Melbourne East West Link) remained lacking in transparency with the government agency acting as promoter once again. Worse, government proposed to take patronage risk, meaning that the private capital would not have been at risk. The project structure was thus further removed from Flyvbjerg's recommendations than the previous round of failed PPP projects. Although now cancelled, the reason for the project cancellation was political, and did not reflect any institutional recognition of these weaknesses.

IMPROVING INFRASTRUCTURE PLANNING AND DELIVERY

As was stated in Elaurant and McDougall (2014), transport planning and investment in Australia has a number of serious problems: lack of consistency in funding, lack of bipartisan support and focus on individual projects, with inadequate attention to systemic issues. To these problems may be added the evidence presented in this paper that there are now two levels to the problem:

1. At the macro level Australia has spen significant sums on transport projects but has achieved a comparatively poor outcome in terms of the quality of the transport system.
2. At the level of individual project delivery, current planning and assessment processes have been insufficient to prevent projects that did not represent good value for money for taxpayers or investors, and economically should not have been built as scoped.

Clearly, there is a need for systemic change in infrastructure planning and delivery. I will now propose some of the changes that might reduce the problems identified.

AN *EFFECTIVE* INDEPENDENT STATUTORY AGENCY FOR INFRASTRUCTURE

The need for a transparent and independent statutory body to make transport investment decisions was identified in Elaurant and McDougall (2014). Similar proposals have been repeated in a number of forums by organisations including the Grattan Institute, Engineers Australia and various industry lobbies. The question is: what is needed for it to be *effective*?

Infrastructure Australia became a statutory body in 2014 and has the potential to fulfil this role, as it already undertakes project assessment and prioritisation. However it has no power other than to make recommendations and that advice may be ignored. The need is for a statutory body in the style of the Reserve Bank of Australia, with decision-making powers:

1. The power to make binding decisions to approve or reject major infrastructure projects (with capital cost > \$100 million AUS in 2015 \$). It is important not to waste capital on unjustifiable projects as well as to fund projects that are needed.
2. The power to allocate a pre-determined stream of government revenue to deliver projects, and/or to raise funds to deliver them. Without the ability to fund approved projects, the body will remain ineffectual.

Ideally, the body should have a stable stream of funds to allocate, ensuring a more predictable level of activity. The rate of investment should be based on long term trends, and benchmarked to other OECD countries. Comparing the geographically similar case of Canada, an amount of 0.6% to 0.7% of GDP would appear sufficient, if efficiently spent.

Funding shares between States should be fixed in a similar fashion to Grants Commission decisions on the allocation of GST revenue. This would give each State an incentive to prioritise its most beneficial transport projects, rather than to identify projects that maximise funding and economic activity, as the current system appears to encourage.

The decisions of the body should be made public together with the reasons, in a similar manner to RBA board meeting notes on interest rate decisions. This ensures transparency, which appears to be a key requirement in preventing the worst cases of project failure.

Ideally this process would occur at a national level. Traditionally transport planning in Australia has been a State level activity, and agreeing reforms of Federal – State funding mechanisms has proven difficult. In the absence of a national body, State level independent statutory infrastructure bodies with these decision making powers would still be of benefit.

Many OECD countries place transport planning decisions in the hands of independent statutory bodies with approval and funding powers. This is done at a national level, such as in several European countries, or at state or metropolitan level, such as in the United States. In some cases these put major project approvals to a popular vote at municipal elections, together with the funding mechanism proposed to pay for them.

PROJECT GOVERNANCE REFORMS

Private capital via PPP projects was designed to manage project cost and demand risks. Reforms are required to improve Australian practice with contracting PPP projects:

1. Standardisation of the form of PPP contracts and financial structures to ensure that contracts are robust and protect investors, while reducing administration and bidding costs. Current Australian practice costs bidders up to \$100 million to prepare a bid.
2. Guidelines for PPP projects need to be expanded to define acceptable governance arrangements. These need to mandate transparency, independence of decision making, and risk allocation, as well as financial parameters. The reported \$1.2 billion "success fee" (Davies, 2014) within

the winning bid of the $6.5 billion Melbourne East West Link illustrates this problem. The success fee represented a 20% cost impost on the project, making an already marginal project almost certainly uneconomic.

3. Terms of PPP contracts do not appear to be in the public interest. PPP concessions have been granted in Australia with concession periods of 30 or more years. UK practice is to grant 20 year concession periods, or less if financial return targets are met sooner. Increasing concession periods beyond 20 years is unlikely to improve project viability.
4. Delivery mechanisms for publically funded (non-PPP) projects also require review:
   a. Contract terms for non-PPP projects should be standard across all States.
   b. Simpler contract forms such as separate or combined Design and Construct contracts should be preferred. Wood (2010) highlighted that Alliance projects tend to have higher outturn costs.
   c. In general, the public interest would appear better served by a delivery of a larger number of smaller projects, and fewer infrastructure “megaprojects”. Smaller projects have on average higher benefit cost ratios (Infrastructure Australia, 2013), suggesting that several smaller projects will result in greater community benefits than the same funds being concentrated in one or two “megaprojects”.
5. The desire to introduce large PPP projects appears to be driven in part by the need to obtain additional funding for project delivery. This skews the scoping and mode choice of the projects. It may be more efficient to deliver projects by conventional (public contract) means, and use alternative mechanisms to finance them.

PLANNING AND PROJECT ASSESSMENT REFORMS

Planning of transport networks and assessment of individual projects also require reform:

1. Australia’s transport analytical capability has atrophied, due to agency budget cuts. Funding is focused on building, with very little focus on capability to know what should be built. The total budget for infrastructure data acquisition, modelling and strategic analysis is less than 1% of the infrastructure capital budget in every mainland State. Project level capital budgets are much larger than project level planning budgets; the latter are typically 2% or less of capital costs.
2. Transport agencies should be required to fund the development and regular updating of transport models of major urban areas. Models and calibration reports should be publically accessible, to inform public debate, and to improve land use planning.
3. Data acquisition should be systematically budgeted and carried out. Currently Australia has no regular freight or transport survey at national level. Australia lags in implementation of modern methods such as travel matrices from smart phone data.
4. Transport and land use agencies should be required to identify and preserve corridors that will be required for future transport infrastructure at the time of development. This was normal practice up to the 1970s. Failure to do so since has contributed to higher costs for surface projects, and the use of costly tunnels. The cost efficiency of Perth projects in the sample highlights the benefits of corridor preservation.
5. Project assessment including demand modelling should be undertaken by an agency independent of the proponent, to avoid the potential for conflict of interest and bias.
6. Assessment (benefit cost) guidelines should be revised to match international practice:
   a. Quantify and compulsorily include factors currently not required including wider economic benefits, health impacts, and environmental impacts (including emissions)
   b. Assessment of public transport project benefits is greatly deficient. In the absence of a commitment to quantify relevant factors in Australian practice, the New Zealand Economic Evaluation Manual or similar should be adopted.
   c. Revise discount rates to reflect long term government borrowing costs. The current 7% discount rate is biased towards projects with short term benefit streams; the UK uses 4%.
   d. A benefit-cost “hurdle rate” higher than 1 should be adopted. When cost risks (10%) and demand risks (15% up to 44% for

PPPs) are taken into account, a project should have a benefit cost ratio of at least 1.5 at the planning stage to ensure that actual project benefits are likely to exceed actual project costs.

ACKNOWLEDGMENT

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LITERATURE CITED

AUSTRALIAN LOCAL GOVERNMENT ASSOCIATION. 2012. The Local Road Funding Gap. Canberra, ACT.

BAIN, R. 2013. Toll Roads: Big Trouble Down Under. Infrastructure Journal, 17 January 2013.

CUTTAREE, V. 2008. Successes and Failures of PPP Projects. World Bank, Europe and Central Asian Region. Warsaw.

DAVIES, A. 2014. What can we learn from the East West Link debacle? The Urbanist blog, December 2014.

DEPARTMENT OF INFRASTRUCTURE AND REGIONAL DEVELOPMENT. 2013. State of Australian Cities. Canberra, ACT

ELAURANT, S. & MCDOUGALL, W. 2014. Politics Funding and Transport, AITPM Conference paper, June 2014.

FLYVBJERG, B. 2003. Megaprojects and Risk: An Anatomy of Ambition. Cambridge University Press. Cambridge, UK.

INFRASTRUCTURE AUSTRALIA. 2013. Infrastructure Australia Priority List and Appraisals. Canberra, ACT, July 2013.

INFRASTRUCTURE AUSTRALIA. 2015. Australian Infrastructure Audit Report. Canberra, ACT.

MARTIN, S. 2013. Costing of Australian urban passenger rail projects 2000-2012: How much did we pay and what did we get? Conference of Railway Engineering (CORE).

OECD ONLINE STATISTICS. 2015. Summary Statistics: Transport Infrastructure, Gross Domestic Product. Electronically accessed May 2015.

PRODUCTIVITY COMMISSION. 2014. Public Infrastructure Inquiry. Canberra, ACT.

SMITH N., BAIN R. & KANOWSKI S. 2011. An Investigation of the Causes of Over-Optimistic Patronage Forecasts for Selected Recent Toll Road Projects. GHD (for the Australian Department of Infrastructure and Transport). Sydney.

UNITED NATIONS DEVELOPMENT PROGRAM. 2014. Human Development Report. July 2014.

WOOD, P. 2010. Comparing Cost Uplift in Infrastructure Delivery Methods: A Case Based Approach. PhD Thesis. Queensland University of Technology.

APPENDIX 1 – NOTES ON STATISTICAL ANALYSIS

1. Unit (Real) Cost per Lane Km: due to substantial right skew a (base 10) log transform was used. Linear regression models were then fitted to investigate the effect of PPP status (PPP vs non-PPP). Bridge projects were omitted from the analyses due to small number (n=3) of observations. Firstly, an interaction term was fitted to test for difference in the effect of PPP status by project type; however, this was not statistically significant (p=0.796) so it was dropped, and a model was fitted testing the overall effect of PPP status, adjusting for project type and year of opening. The difference in mean log(cost) between PPP and non-PPP projects was not statistically significant (estimated difference on the log scale 0.05 (-0.23, 0.34), p=070).
2. Cost Risk: this outcome also had substantial right skew; however a straightforward log transform was not possible due to the presence of negative values. Instead a range of approaches were used:
   (a) The values were first transformed to be strictly positive (by subtracting the minimum value – 1) before log transforming, and fitting a linear regression model in the same manner as for real cost per lane km. There was no evidence for difference of PPP effect by project type (p=0.348), and in the multivariable model (effect of PPP adjusting for project type and year of opening) there was no significant difference between PPP and non-PPP projects (difference on log scale -0.16 (-0.47, 0.15, p=0.311).
   (b) Wilcoxon rank sum (non-parametric) tests were used (with original Cost Overrun values, i.e. not log transformed) to test for difference between PPP and non-PPP projects separately by project type (i.e.

PPP vs non-PPP for Surface projects, and PPP vs non-PPP for Tunnel projects). In neither case was the difference statistically significant (Surface: $p=0.861$; Tunnel $p=0.117$).

3. Demand Risk (Forecast Accuracy) %: this outcome had a sufficiently symmetric distribution that transformation was not judged necessary. Linear regression models were fitted as above. There was no evidence for different effects of PPP status by project type ($p=0.949$). In the multivariable model testing for the effect of PPP status adjusting for project type and year of opening, the effect of PPP status was highly statistically significant ($p<0.001$) with an estimated difference (PPP minus non-PPP) of -44.29 (-61.93, -26.64).

AUTHOR PROFILES

Scott Elaurant is an engineer economist who has worked for thirty years in transport planning in Australia, New Zealand and South East Asia. He has experience in network and concept planning, transport demand modelling, traffic capacity, business cases, wider economic benefits and financial analysis. He was head of discipline for transport planning in Queensland Main Roads prior to joining Jacobs. Recent projects Scott has worked on include the Adelaide South Road corridor, Glenelg Tram extension, and Auckland Light Rail. Scott gathered the project database and wrote the transport aspects of the paper.

Jennie Louise is a statistician at the Data Management and Analysis Centre (DMAC), University of Adelaide. Jennie has spent more than ten years as an academic. She is currently working mainly in clinical trials. Jennie undertook the statistical analysis and wrote the statistical reporting aspects of the paper

COOLOOLA NATIONAL PARK – ANOTHER PERSPECTIVE ON THE BJELKE-PETERSEN GOVERNMENT

TURNER, R.

INTRODUCTION

'Don't go!' This was the advice of alarmed friends and family prior to our moving to Queensland. It was both corrupt and a police State, they said, headed by the odious Premier Joh Bjelke-Petersen. He was the Premier of a government who declared a 30-day State of Emergency over a football match and used secret deals to ensure brute police force was used to break the anti-apartheid protests of 1971. I decided to stay away from politics but, within two years I was to personally see a curious contradiction in the persona of Premier Joh.

After working for the National Parks Service in Victoria for 17 years I arrived in Gympie, in April 1978. The Queensland National Parks and Wildlife Service regional headquarters was based in Maryborough, but the Gympie City Council had somehow extracted an undertaking from our Director, Dr Graham Saunders, to establish a headquarters in Gympie. As District Ranger, I was second in charge of a region that covered 35 national parks. The two most important (and controversial) parks were Cooloola and Noosa. Some 25,030 hectares of the Cooloola sand mass had been gazetted as the Cooloola National Park in 1975. The Forestry Department retained the more important commercial forests and most of the diverse rainforests, all growing on sand.

DEVELOPMENT PRESSURES ON THE COOLOOLA REGION

Managed by the Queensland Forestry Department since 1925 as State Forest 451, the Cooloola area encompassed two local authorities. The Widgee Shire, centred around Gympie, was a farmer-based council concerned heavily at that time with roads and rates. Much of the council area was non-rateable State forest. There is little doubt Council – and some residents – had developed a jealousy towards their southern neighbour, the Noosa Shire, with its developing coastal areas and seemingly unlimited potential for further expansion. The official motto for the Widgee Council was 'Develop and Prosper', and they considered they had been treated poorly with declaration of Cooloola as a large national park.

One month before Cooloola National Park was gazetted, Council obtained the right to draw water from Teewah Creek (and Seary's Creek) in the State forest. This led to a poorly located gravel road and overhead power lines across a treeless heath plain of considerable wildflower appeal after the national park was declared. Much of the water was destined to be used in the bayside village development (now known as Cooloola Cove). This former Crown land had been developed for stock grazing, then converted into a 1600 block subdivision. Council advocated a network of roads across the Cooloola area. They obtained funds to improve an old logging track to Freshwater, 'for tourism', and created a maintenance problem for Forestry. At the same time Cudgen Rutile RZ, a sand mining company, was exerting pressure on the Forestry Department initially to allow use of this track for egress of heavily laden trucks carrying mineral sands to the Gympie rail, then for delivery of bulk fuel through the rainforest to the beach.

Widgee Shire Council sought approval for a 360ha. housing development on State Forest above the coloured sand cliffs near Rainbow Beach. They also surveyed an 8km road from Rainbow Beach to Double Island Point for Queensland Titanium Mines Pty Ltd, without the authority of the Department of Forestry. Council intended to 'restore' the active Carlo Sand Blow to facilitate access to both areas. Co-incidentally, the mining companies had found very rich deposits of mineral sands near Double Island Point. An interstate interest had $5 million ready to build an international resort there at the conclusion of mining. Council also foresaw an adjacent township development. Council were pressing for a 29,960 hectare wallum pastoral development scheme across the Western Catchment of the Noosa River, and southerly to their border with the Noosa Shire. These treeless Noosa Plains and river catchment were prime habitat for the rare ground parrot, grass owl, southern emu wren and other locally uncommon birds such as the brolga, jabiru, emu and red-winged parrot. Council's 1981 town planning maps confirmed a proposed jet airport where Forestry had recently cleared and established a pine plantation on the edge of the catchment.

The incumbent Queensland Government Member for Gympie at the time, had previously given an undertaking to have a pulp mill built in the district. The Forestry response was to stress the necessity of needing an additional 10,000 hectares of land on which to plant pines to guarantee the success of the mill. The State Forest-controlled Western Catchment abutting and westerly of recently gazetted Cooloola National Park was their obvious choice. However, the local District Forester preferred to see the area added to the park. His second choice was to plant the area to pines to frustrate what he termed 'beef barons', or 'grass pirates'. Conservationists were pressing hard to have the Western Catchment area incorporated into the national park. Its different soil type had been defined as the Womalah Landscape (Coaldrake, 1961). A recent flora survey had listed over 100 different plants not recorded in the existing park. Conservationists also argued that clearing the catchment could be disastrous for the existing park and lower reaches of the river with its system of shallow lakes, leading to increased siltation and possible closure of the river mouth.

A sister group of the Noosa Parks Association, known as the Cooloola Committee, was formed in Brisbane in 1970. This group petitioned the Queensland Parliament and targeted marginal electoral seats, which caused a revolt of sorts within government ranks. Nervous back-benchers demanded opposition to the sand mining in Cooloola and over-ruled the Cabinet. The Premier used his casting vote to keep his position.

PREMIER JOH BJELKE-PETERSEN INTERVENES

Given these competing arguments, the Premier now wished to inspect the area and make up his own mind, without the presence of any lobbyists. He had almost lost his support in Cabinet over Cooloola a few years earlier. I knew the area, and was on the spot – in more ways than one! In September 1980, I received instructions to meet the Premier at the Gympie airport for an aerial and ground inspection of the Cooloola area, particularly the Western Catchment of the Noosa River. The trip was to be kept absolutely secret; not even staff in my office were to know. Threats had previously been made on the Premier's life.

I contacted the Cooloola Overseer and described the site I had started to clear for a picnic area. 'I know you are busy but you are to install a picnic table, fireplace and rubbish bin there. This must be done before next Tuesday,' I instructed! The day appointed for the inspection duly arrived and, to complicate matters, it coincided with a visit by another senior Minister who was scheduled to inspect the police station and racecourse with Shire Councillors on the same morning. The Premier, his private secretary Peter McDonald and pilot Beryl Young arrived as arranged and I invited the party to accompany me in a vehicle borrowed from Forestry. Approaching the Wolvi area I outlined the issue, especially the argument that Forestry needed an extra 10,000 hectares of land on which to plant pines. As we descended the ranges and drove along the Wolvi-Kin Kin Road, I pointed out former private grazing lands recently purchased by Forestry for planting pines. Considering the costs of clearing untouched native forests, these and further farm-land purchases seemed to me to be a better way to expand the pine plantations than incurring the costs and objections associated with clearing in the upper part of a river catchment, with many foreseeable problems. Cost savings at that time were in the order of $200 per hectare. Within the upper catchment, there were also large tracts of swamp lands unsuitable for plantations, and I pointed out that Forestry were disposed to demonstrate their multiple use of the environment by maintaining strips of native bushland within their plantations. In reality, the residual 'environmental reserves' were either too swampy or too rocky to plant and were managed as firebreaks between blocks of pines, with frequent and sometimes hot burning.

As we proceeded towards Harrys Hut and the Noosa River, I was surprised at Premier Joh's excited response towards a swamp wallaby that hopped across the road. A little further along he insisted we back up to have a look at a carpet python, again with that excited response to seeing the reptile. The Cooloola Way, having not been long opened by council as a tourist road, was still in a reasonable condition and it traversed across part of the land he was to inspect. I was able to show him the chevron chew marks on trees along the route resulting from the feeding habits of the rare yellow-bellied glider. Arriving at a brand new picnic area along the Freshwater Track I saw, with pleasure, the Cooloola Overseer had complied with my wishes. Peter McDonald busied himself lighting the fire and prepared to barbecue the meat. I prepared a Schweppes lime cordial drink I believed the Premier favoured. Beryl Young unpacked the meal my wife, Yvonne, had prepared. The Premier, seated at the table and looking around, started to tell me how

he had nearly lost his Premiership over the Cooloola area. Bags and bags containing some fifteen thousand cards protesting proposals to sand-mine the Cooloola sand mass had arrived at his office. He had stared down his colleagues and narrowly won the day, and the area had become a national park. He had often flown over the area and now, at long last, here he was, right in the middle of tall, dense and silent rain forest. He was ecstatic; it was 'Beautiful, just beautiful', he kept repeating during our stay.

I told the Premier how volunteers were helping to construct walking tracks in the area and of a previous visit by another of his cabinet colleagues, and how he had named the nearby picnic area 'Quandong'. I had searched Zachariah Skyring's Kabi vocabulary and found the word 'bymien', meaning fig. I pointed out several strangler fig trees suggesting it seemed to be an appropriate name for the area where we were sitting, hinting that he might care to emulate his colleague. The Premier in true political style, rose to the occasion – and his feet – saying 'I, Joh, in the presence of Beryl Young, Peter McDonald, and Ron Turner, do hereby declare this Bymien Picnic Area open'. After lunch, we all walked the two kilometres to Lake Poona with its fringing forest, at which point the Premier sat on the sand at the water's edge and kicked off his shoes. His shoulders seemed to visibly relax as he enjoyed the pristine surroundings, so quiet and still. There was not another soul about, just the four of us.

On the return journey to the Gympie airport, the Premier broached what I considered to be the very sensitive issue of the pulp mill asking, 'What is your opinion?' and 'Do you think it is a good project?' Neither question was particularly welcome for they were loaded with politics. I tried to change the subject. 'No, no', he said 'I want to know your opinion'. I referred to a recent newspaper report in *The Gympie Times* wherein the engineer in charge of the local Water Resources Commission office had been reported as stating there was insufficient water in Lake Borumba – the only water storage in the Gympie district – to operate a pulp mill. Describing the horrible tan colour and frothing of paper mill waste water from Rosedale pouring into the western end of the Gippsland Lakes in eastern Victoria, I posed two questions for any local mill: where would the water come from, and where would the considerable effluent go? There appeared to be two choices: pump the effluent into either the Mary River with its localised and rare Queensland lungfish, or overland to the Sandy Straits with resultant problems in each area.

Arriving back at the Gympie airport, I was interested to note two policemen guarding the 'Joh Jet'. Their appraisal of the situation was that the senior Government Minister had arrived soon after my party had left. Apparently that senior Minister flew into a tantrum demanding to know 'What is going on?' He didn't know why the Premier was in Gympie, nor did the local member, nor did the Council, until they were undoubtedly told by workmen that the Premier had left with the local park ranger. The senior Minister was not amused. In fact, I was told he was furious and castigated police severely as the 'Joh Jet' wasn't under guard! Obviously, Council were not amused either. On board the 'Joh Jet' I gave Beryl a compass course to follow. As the plane circled over the Cootharaba area, I outlined the recent logging and pastoral history of Elanda, stating my belief the Commonwealth Government, who owned the land, was about to hand the area back to the State for national park purposes on condition that the current lessee was granted a lease on a foreshore section. I explained the area was heavily infested with the noxious weed groundsel, and that it would take a long time and a lot of money to revegetate. I thought this area, if planted to pines in addition to the Wolvi lands, would almost reach the 10,000 hectares Forestry were seeking. Additionally, the Australian Paper Manufacturing group had recently established extensive areas of pine plantation on former grazing lands just to the west of Elanda.

We flew north along the Noosa River valley, then started to circle lazily over the Western Catchment. The land below was wet, very wet, and I made the observation to the Premier: 'Looks very wet down there'. There was something in his reply; something in the way he slowly said 'Yeesss' which caused me to 'rest my case' and say no more. I was surprised to discover in my vehicle, after the plane bearing the Premier had departed, a memorandum written by the permanent head of the Department of Forestry to his Minister outlining the Forestry case for a pulp mill. Forestry had, I noted, become very interested in a cattle property owned by the Tinana Development Company in the Neerdie area, just north-west of the Toolara Forestry headquarters. This would satisfy their requirements should they not be allowed to plant pines within the Western Catchment. The company

was willing to sell 10,345 hectares at an average price of $517 per hectare, and a valuer's report on the property was attached. This price even included the cost of fertiliser recently applied to the land. Forestry were seeking assistance with a $1.2 million shortfall to purchase this area. Now what? I telephoned the information, then posted the report to QNPWS head office for their attention, but the question remained in my mind: was the report left in my vehicle accidentally, or deliberately?

A week later I was informed the Western Catchment would be added to Cooloola National Park. Together with other lands, the area protected in the park increased by almost 18,000 hectares, in 1983/84.

KILKIVAN WANTS A NATIONAL PARK

After the Widgee Shire my involvement with the Kilkivan Shire Council to the west of Gympie was both pleasing, and welcome. The Chairman and Shire Clerk were cooperative, as were other councillors, and staff. Council actually wanted a national park or similar land tenure in their area to encourage passing tourist traffic to stay overnight in the town. This was really a laid-back council, and I liked their friendly sincerity of 'Come and have a cup of tea and a biscuit, Ron, and tell us what you think' attitude. I travelled with them visiting the different areas they considered had potential. The best by far was the Mudlo Beauty Spot, just to the north of town and managed by the Department of Forestry. I spent an interesting day there with two botanists. They compiled the first detailed plant list for the area advising that these semi-evergreen vine thickets (or 'dry rain-forests'), were not well known botanically and contained a number of threatened species. A major difficulty for conversion seemed to be the presence of two inactive gold mining leases on the north-western edge of the area.

I was aware of a friendly relationship between the local shire chairman and the Premier, and I broached this friendship with the chairman on one occasion. He was curious at my asking this personal question. I explained that the Premier was scheduled to officially open a nearby gold mine along Rossmore Creek, then travel by helicopter westerly to open a feedlot at Cinnanbar. He readily accepted my suggestion he try to get the Premier to fly over the Mudlo area en-route. 'Leave it with me', he said, 'I will see what I can do'! Shortly afterwards I was surprised, but pleased, to receive an instruction to present myself at the gold mine for its official opening on 2 September 1987, then to accompany the Premier and Shire Chairman in the helicopter. I felt uncomfortable in the presence of miners and other invited guests. Eventually, I met up with the Premier reminding him of our previous day together at Cooloola. He responded, with some warmth, 'That's nice!'

I strapped myself into the helicopter and gave the pilot directions to the Mudlo Gap, soon clearly visible. From the ground this was an impressive stand of hoop pine, jutting up from and over-topping the semi-evergreen vine thickets below. From the air it was both stunning and spectacular. Sir Joh, sitting in the front of the helicopter was, again enthusiastic saying, 'This is just beautiful. We have got to have this area protected. Have you got a map?'. He instructed the pilot to circle back for another look saying to the chairman 'Get me a map of the area you want and we will have it protected'.

There are times when I confess to pleasurable work-related moments and, alighting from the helicopter after the Premier at the Cinnanbar feedlot, my feet seemed barely to touch the ground. The support of a shire chairman to have the Mudlo area made into a national park had now won the enthusiastic backing of the Premier.

In the earlier example of Cooloola and now Mudlo, the scientific arguments were on hand for preserving key areas for conservation but, once again, I saw firsthand the invaluable impetus of quiet, behind the scenes diplomacy, to gain the vital support of key decision makers. However, Premier Bjelke-Petersen resigned from Parliament a week after his inspection of Mudlo. He became embroiled in the debacle which led to the Fitzgerald Enquiry. His resignation and those two mining leases caused the action to declare Mudlo a national park to be delayed for some years.

MY OPINION BASED ON EXPERIENCE

My two asociations with Premier Bjelke-Pteresen in 1980 and 1987 allowed me to form my own opinion of his attitude to the environment. Despite his public anti-green image – as portrayed to the country at large – he personally supported conservation when he was able to get away from lobbyists and advisors and make up his own mind. I found it fascinating to recently read Paul Sattler's account (Sattler, 2014) of meeting Premier Bjelke-Petersen in 1972. From a publicly hostile attitude towards conservation, the Bjelke-Petersen Government went on to support the creation of the Queensland National Parks and Wildlife Service, and soon after, support major extensions to the national parks estate.

LITERATURE CITED

COALDRAKE, J.E. 1961. Eco-system of the coastal lowlands, southern Queensland. (CSIRO Bulletin)

SATTLER, P. 2014. Five Million Hectares: An historical account of the expansion of Queensland's national parks, 1975 – 2000. Proceedings of the Royal Society of Queensland 119: 53-62.

AUTHOR PROFILE

Ron Turner was born at Geelong, Victoria in 1936. He completed trade courses and national service in the Royal Australian Navy. He spent three and a half years in the mountainous country of the South Island of New Zealand which focussed his future years on national park management in Victoria and Queensland.

He was appointed as District Ranger, Gympie in 1978 with the Queensland National Parks and Wildlife Service. One of the 35 parks he was involved with in Queensland was Cooloola. His latter years with QNPWS focussed on wildlife management. He is married with four children. Ron is retired and lives at Gympie.

WHEN IS STOCK GRAZING AN APPROPRIATE 'TOOL' FOR REDUCING *CENCHRUS CILIARIS* (BUFFEL GRASS) ON CONSERVATION RESERVES?

MELZER R.I.

Buffel grass (*Cenchrus ciliaris*) – one of the most commercially important pasture species in Queensland – is widely recognised as a serious environmental weed in natural systems. It poses a significant threat to species, ecosystem and landscape values on conservation reserves through direct (e.g. competition) and indirect (e.g. altered fire regimes) impacts. Of particular concern are the threats to fire-sensitive ecosystems and the species dependent on them.

This paper provides an overview of the characteristics and impacts of buffel grass, a summary of control strategies and actions that are available - their limitations, benefits and negative impacts. It provides the context and information necessary to guide an informed decision about when grazing may be an appropriate tool to include in an integrated control strategy on conservation reserves to reduce the impacts of buffel grass on biological values.

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INTRODUCTION

The management of buffel grass to reduce impacts on estate values requires an integrated approach. The latter will often include techniques such as manual, mechanical and herbicide control. However, none of these techniques are appropriate options over the large areas of some reserves where buffel grass is already well established and abundant. Fire, which can be used as a broad-scale management tool for a range of purposes, is widely recognised as exacerbating the impacts of buffel grass. Nevertheless, it may be appropriate in fire-adapted vegetation as part of an integrated control program, and otherwise will be required from time to time to maintain species and ecosystems. Biological control, through stock grazing, is currently considered the only feasible 'tool' for managing buffel grass to achieve conservation outcomes where the infestation is extensive and the native vegetation is fire-sensitive.

The use of stock grazing as a management tool on conservation reserves is controversial because it is a novel approach that is seemingly counter to the principle of excluding non-native fauna in order to conserve natural processes and resources, and it is open to misunderstanding and misuse. There are however, examples where stock grazing is already used, and accepted, as an effective management tool for achieving particular conservation outcomes. For example, sheep grazing is being used to maintain an open grassland structure for the vulnerable plains-wanderer (*Pedionomus torquatus*) on Oolambeyan National Park in New South Wales (NSW Govt, 2011; NSW NPWS, 2012). Cattle grazing is used on Albinia Regional Park (Melzer A., 2011; Melzer R., 2011; Melzer, in prep.) and Taunton National Park (Special Management Area) in Queensland to facilitate the recovery of fire-sensitive regrowth. On Taunton National Park its purpose is also to promote and maintain habitat for the endangered bridled nail-tail wallaby (*Onychogalea fraenata*) (Melzer, 2012).

The fundamental premise is that, in an Australian context, stock grazing should only be considered for use on conservation reserves such as national parks when there is no other effective means to protect or restore a significant natural value. As such, the grazing regime will be tailored to achieve an explicit conservation outcome rather than a commercial one. A grazing regime that is suitable for achieving a conservation outcome may in fact be detrimental from a commercial perspective. The conservation gains achieved from using grazing as a management tool must far outweigh any negative impacts.

This paper draws together research and experience from Queensland and inter-state government professional and operational staff, as well as from graziers and the scientific literature. The paper draws heavily on an earlier report exploring the issue of

using cattle grazing as a management tool to achieve conservation outcomes on Taunton National Park {previously Taunton National Park (Scientific)} (Melzer, 2009).

The importance and value of buffel grass to the pastoral industry (Friedel et al., 2006; Johnson, 2006; Friedel et al., 2008) is acknowledged but not discussed in the document because it is the impact and management of buffel grass on conservation reserves that is at issue.

BUFFEL GRASS

ORIGIN AND DISTRIBUTION

Buffel grass is native to tropical and subtropical arid regions of Africa and western Asia (Marshall et al., 2012). It is thought to have been accidentally introduced to central and north-western Australia as early as the 1870's in camel harness, and it subsequently naturalised in some areas. From the 1920's it was actively introduced and promoted as a pasture species. It was first planted in Queensland in Cloncurry in 1926, and in Rockhampton in 1928 (Humphries, 1967 cited in Greenfield, 2007). By the 1930's it had been sown in several other districts in Queensland for pasture (Eyre et al., 2009; Marshall et al., 2012). It has also been used in Australia for mine site rehabilitation, erosion control and dust control (Keetch, 1981 cited in Friedel et al., 2006; Humphries et al., 1991; Marshall et al., 2012).

By 2000, buffel grass pastures were estimated to cover between 30 and 50 million hectares of Queensland (Hannah and Thurgate, 2001). Modelling based on the species' soil and climatic requirements indicates that about 68% of Australia is suitable to highly suitable for buffel grass with only 19% being totally unsuitable. The majority of Queensland is predicted to be suitable or highly suitable with the Channel Country, Mt Isa Inlier/Northern Uplands, Einasleigh Uplands and northern Brigalow Belt predicted to have the highest suitability for buffel grass growth (Lawson et al., 2004). Buffel grass currently occurs over extensive areas of rangeland in Queensland, Northern Territory, Western Australia, South Australia and New South Wales (Smyth et al., 2009;, Marshall et al., 2012).

BIOLOGY AND CHARACTERISTICS

Buffel grass is a long-lived (individual tussocks may live up to 20 years – McIvor, 2007 and Latz, 1997 cited in Friedel et al., 2007), robust, perennial, C4 tussock grass with a deep root system and swollen stem bases that store carbohydrate reserves (Marshall et al., 2012), particularly towards the end of the growing season (J. Chamberlain pers. comm. in Melzer, 2003).

It reproduces by seed (it is typically apomictic) or vegetatively through rhizomes and stolons (De Lisle, 1963 cited in Franks, 2002; Greenfield, 2007; Marshall et al., 2012). It has prolonged flowering and fruiting periods and produces seed in abundance (Franks et al., 2000). Estimates of seed viability range from two to 30 years (Winkworth, 1971 cited in Greenfield, 2007; Friedel et al., 2007). Seeds rarely survive ingestion by cattle (Greenfield, 2007).

The fluffy seed is readily dispersed by wind and water, on clothing or animal fur/hair and on vehicles, and so spread is particularly common along drainage lines and roads (Puckey and Albrecht, 2004; Biosecurity SA, 2012; Marshall et al., 2012). Unintentional management-facilitated spread along tracks and fire control lines is a major invasion pathway (author pers. obs.).

Seeds germinate rapidly with suitable soil moisture and the germinants can flower and set seed within about six weeks and when only a few centimetres tall (Melzer and Porter, 2002; CRC Weed Management, 2008). Vegetative regrowth also occurs rapidly after rainfall.

Seedlings are able to establish in bare areas whether these bare areas occur naturally or as a result of disturbance (McIvor, 2003; Marshall et al., 2012). Even minor soil disturbance or removal of litter cover facilitates its establishment (Franks, 2002; Jackson, 2004; Eyre et al., 2009). Fairfax and Fensham (2000) note that it can expand rapidly into remnant native vegetation that is otherwise undisturbed except for grazing and occasional burning.

Evidence that fire facilitates invasion is limited and may vary depending on environmental conditions (Fensham et al., 2013). Anecdotal evidence at Taunton National Park (G. Porter pers. comm. in Melzer, 2005; J. Wyland pers. comm. in Melzer, 2008) suggests that fire is a factor in promoting the spread of buffel into brigalow ecosystems, potentially by altering the physical properties of the soil surface (R. Johnson pers. comm.). That is, fire may provide an increased opportunity for seedling recruitment and therefore spread. Buffel grass is highly fire-adapted and once established is promoted by fire (Low, 1997 cited in Franks 2000; Franks et al., 2000; Tix, 2000; Tu, 2002;

Butler & Fairfax, 2003; Miller, 2003; Miller et al., 2010; Desert Knowledge CRC, 2005; Smyth et al., 2009; Marshall et al., 2012).

Buffel grass can be slow to establish initially but may then spread rapidly under favourable seasonal conditions (CRC Weed Management, 2008). Invasion and spread can be substantially enhanced during periods of above average rainfall (Friedel et al., 2006) particularly following drought (Cavaye, 1991 cited in Eyre et al., 2009; Fensham et al., 2013). A nearby source of abundant seed, particularly an upwind/water source, is a significant factor in successful invasion (Eyre et al., 2009; Fensham et al., 2013).

It will tolerate a wide range of climatic conditions including very high temperatures and annual rainfall averages from 180mm (NSW Department of Primary Industries, 2004) to 2670mm (Tix, 2000). Establishment is said not to occur where the mean annual minimum temperature drops below 5°C (Cox et al., 1988 cited in Marshall et al., 2012).

It will grow on a wide range of soil types although the 'preference' is for sandy and sandy loam soils (Lawson et al., 2004) with available phosphorus content of at least 10mg/kg, a loose friable surface and well structured, freely draining subsoil and soil depth of at least 0.3m (Muller, 2000). Some of the most suitable soils in Queensland for buffel grass establishment include red earths with a friable surface, lighter clays in brigalow and brigalow/belah areas, sandy soils with moderate phosphorus content (e.g. river frontage) and soils previously under softwood scrub and gidgee (Cavaye, 1991 cited in Marshall et al., 2012). Some varieties are adapted to heavier clays (NSW Department of Primary Industries, 2004).

Buffel grass generally has poor tolerance for waterlogging (NSW Department of Primary Industries, 2004) but some cultivars have been developed to tolerate periodic flooding (Marshall et al., 2012).

The deep, robust root system, storage of carbohydrates in the swollen stem bases, and ability to reproduce vegetatively via rhizomes and stolons contribute to its ability to withstand and rapidly recover from heavy grazing, trampling, fire, frost and drought (Dixon et al., 2002; Franks et al., 2000; Tu, 2002; Puckney and Albrecht, 2004). Buffel grass is said to be the most drought tolerant of the introduced grasses for the 500-1000mm rainfall belt of Central Queensland (Graham, 2001).

It currently has no significant natural pests although some pests and diseases occasionally cause dieback. The importance of buffel grass to the pastoral industry precludes exploration of pest or disease-mediated biological control.

IMPACTS ON BIODIVERSITY AND LANDSCAPE VALUES

There is a large and growing body of literature on the impacts of buffel grass on biodiversity and landscape values. The characteristics that make buffel grass suitable as a productive and persistent pasture species also make it an aggressive and persistent environmental weed.

Buffel grass was identified by Humphries et al., (1991) as one of Australia's top 18 environmental weeds. These were selected on the basis of their potential to threaten or destroy large areas of an ecosystem over its continental range. Three ecological communities in Queensland that are listed as endangered under the Commonwealth EPBC Act are threatened by buffel grass: brigalow (*Acacia harpophylla* – whether dominant or subdominant); semi-evergreen vine thickets in the Brigalow Belt; and bluegrass (*Dichanthium* spp.) grasslands of the Brigalow Belt (CRC Weed Management, 2008). Other significant, fire-sensitive *Acacia* dominated communities are also threatened by buffel grass including gidgee (*A. cambagei*) and blackwood (*A. argyrodendron*).

Buffel grass has been identified as a major threat to biodiversity in the regional natural resource strategies of the South Australian Arid Lands, Western Australian Rangelands, Northern Territory and Fitzroy in Queensland (CRC Weed Management, 2008). It was formerly declared a weed in South Australia in early 2015 under the Natural Resources Management Act (2004).

Internationally, buffel grass is recognised as a major threat to native ecosystems ranging from grasslands in Hawaii, to desert shrub and thorn scrub in arid upland regions of the United States, and the iconic saguaro cactus communities of the Sonoran Desert in Mexico (Tix, 2000; Tu, 2002; Arriaga et al., 2004; ASDMSV, 2008). It has been declared a noxious weed in Arizona (Franks, 2002).

Buffel grass commonly forms dense stands thereby out-competing native species, altering the structure of the ground stratum, and resulting in a loss of

floristic diversity (Humphries et al., 1991; Franks, 2000; Fairfax and Fensham, 2000; Jackson, 2005; Fensham et al., 2015). Buffel grass has an allelopathic effect on some species (Nurdin and Fulbright, 1990; Melzer, 2013) which would exacerbate these effects. Significant negative impacts on floristic richness were detected by Franks (2000) in eucalypt woodlands in central Queensland once buffel grass cover was 5-25%, and by Fairfax and Fensham (2000) in brigalow and eucalypt woodland when exotic pasture cover (mostly buffel grass) was greater than 10%. Fensham et al., (2015) found a linear decline in species richness with increasing buffel grass cover in plots ranging from $1m^2$ to $1000m^2$ in a eucalypt savanna ecosystem in central Queensland. With moderate levels of buffel grass cover the reduction in species richness was about 40%. Native perennial grasses were the most effected. The influence of buffel grass on the composition of the ground stratum vegetation in gneissic hill habitat in central Australia was detectable with no more than about 20% buffel grass cover (Smyth et al., 2009).

The relative homogeneity of dense buffel stands is known to impact on native fauna in central Queensland, encouraging some to the detriment of others, and causing an overall decline in species richness (Hannah and Thurgate, 2001; Hannah et al., 2007). Specialist granivores, such as finches, become rare in landscapes dominated by buffel grass whereas some other bird species seem to benefit (Franks et al., 2000). The native delicate mouse (*Pseudomys delicatulus*) was found to decline as the cover of buffel grass increased in eucalypt woodlands in central Queensland whereas the introduced house mouse increased (Ludwig et al., 2000 cited in Puckey and Albrecht, 2004). Best (1998) found significant changes in the structure and composition of central Australian invertebrate communities with buffel grass invasion – most invertebrate orders suffered a decline in abundance and the total number of species and orders declined significantly. Variation in the composition of ground-dwelling birds and some ants in gneissic hill habitat in central Australia was attributable to variation in buffel grass cover (Smyth et al., 2009).

The rapid recovery of buffel grass after fire, and its' substantially greater biomass than that of the native species it displaces (CSIRO undated; Latz, 1991 cited in Miller et al., 2010; Humphries, 1993 cited in Franks, 2002), alters the intensity, frequency and extent of fires, typically forming a positive feedback loop whereby buffel grass is increasingly favoured (Franks et al., 2000; Franks, 2002; CRC Weed Management, 2008; Marshall et al., 2012). Altered fire regimes, at least in some ecosystems, may be the most significant impact of buffel grass invasion (Marshall et al., 2012; Schlesinger et al., 2013) altering, sometimes irreversibly, the structure and composition of communities (Butler and Fairfax, 2003; Friedel et al., 2006; CRC Weed Management, 2008; Miller et al., 2010). The impact can be particularly severe where fires occur during the dry season and result in loss of trees – particularly hollow-bearing trees, shrub layers, and fallen logs and leave few or no unburnt patches within a landscape. The aforementioned refuges and niches are all important, and in some cases critical, fauna habitat.

Spatial and temporal mosaic or patch burning is recommended in many native ecosystems in order to provide for the range of habitat requirements of the flora and fauna species and to prevent widespread, unplanned fires. Mosaic burning becomes much more difficult to achieve in areas invaded by buffel grass because it provides a relatively continuous cover of flammable material that recovers rapidly after fire (Melzer, 2005; CRC Weed Management, 2008).

The impacts of altered fire regimes on fire-adapted communities are of concern, but for fire-sensitive communities they can be catastrophic. Fire-sensitive ecosystems in this discussion are those which are fundamentally changed by fire in terms of their structure, composition and function – with canopy species, and often species in the substrata, frequently killed by fire or reduced to the rootstock, and not usually having fire-promoted germination. Under natural conditions fire-sensitive communities are often ‘self-protecting’ as their structure and microclimate, and sometimes location, usually preclude fire. When buffel grass, or indeed any other high biomass exotic grass, grows adjacent to or penetrates into a fire-sensitive community, fire can carry into it and open up the canopy. The edges (or extent of the community impacted) become more prone to degradation through further weed invasion and future fires; a ‘downward spiral’ is initiated and the community is progressively degraded (CRC Weed Management, 2008). Butler and Fairfax (2003) report on a particular case study in remnant gidgee (*A. cambagei*) and brigalow (*A. harpophylla*) woodland (an endangered regional ecosystem) in Mazeppa National Park, central Queensland that is illustrative of the phenomenon.

Unfortunately, the Mazeppa example is not an isolated one. Other parks in central Queensland where fire-sensitive ecosystems are impacted by altered fire regimes as a result of buffel grass invasion include, but are not limited to, Epping, Nairana, Palmgrove, Taunton and Carnarvon. On these parks, one or more of the following ecosystems are at risk: gidgee (*A. cambagei*), brigalow (*A. harpophylla*), blackwood (*A. argyrodendron*), semi-evergreen vine thicket/ forest. The problem of buffel-mediated fire impacts on fire-sensitive ecosystems is a widely and commonly occurring conservation issue elsewhere in Australia (Friedel et al., 2006) and overseas (Tu, 2002; ASDMSV, 2008).

BUFFEL GRASS MANAGEMENT

Guidelines for the management of buffel grass on conservation reserves in Queensland were compiled by Melzer and Porter (2002). The guidelines address three circumstances (1-3 below) and focus on prevention of establishment, containment, minimisation of impacts and targeted reduction of infestations. This approach is also recommended by the CRC Weed Management (2003) in their weed management guide for buffel grass. The circumstances are:

1. Reserves or parts of reserves where buffel grass is not currently present but conditions (e.g. soil type, climate) are suitable for its establishment and there is a seed source nearby;
2. Reserves or parts of reserves where buffel grass occurs as scattered plants and/or in sparse to dense patches in relatively restricted areas;
3. Reserves or parts of reserves where buffel grass dominates large areas.

Preventing establishment is by far the most sensible and cost effective approach. It requires a 'cultural shift' such that a new buffel grass infestation is viewed in the same way that a patch of *Parthenium* is currently viewed – it is avoided in a vehicle and controlled as soon as possible. Buffel grass infestations often start along roadsides and gradually expand into adjacent communities. They should be controlled before the expansion occurs.

CONTROL OPTIONS – OTHER THAN STOCK GRAZING

Manual removal, mechanical and herbicide control, and planned burning are 'tools' that contribute to integrated buffel grass management programs. Regrowth enhancement (defined here as promoting rapid 'woody thickening') – whereby measures are taken to rapidly increase the density of a vegetation community, or the edge of the community, to minimise the risk of buffel grass invasion or to shade out established buffel – may be applicable in some circumstances as part of an integrated control program. The limitations, benefits and negative impacts of these control options are discussed in brief below.

Biological control mediated by pathogens or insects is never likely to be an option because of the importance of buffel grass to the pastoral industry and so is not discussed here.

MANUAL REMOVAL

Manual removal can be effective, particularly in combination with herbicide, for small and/or isolated areas (CRC Weed Management, 2008).

Mature buffel plants have a large, tough crown and deep root mass that make it very difficult to remove (Rutman, 1998 cited in Tu, 2002; CRC Weed Management, 2008). The soil disturbance caused by manual removal promotes buffel germination and establishment and so follow-up is essential. Physical removal of buffel was trialled in a Queensland reserve but in the absence of follow-up resulted in a denser sward than was present prior to the control action (Melzer, 2001).

Manual removal (grubbing out individual plants) in combination with herbicide was used in a 54ha core area of the Alice Springs Desert Park to control buffel grass. The project commenced in 1996 and was successful in removing buffel grass plants from a large proportion of the core area. It was however labour intensive, involving volunteers and community work programs, and will require regular follow-up (CRC Weed Management, 2008). A similar program is underway in key areas of Uluru-Kata Tjuta National Park where the mapped extent of buffel in 2003 was 300ha (a ten-fold increase compared to 1991). Here, crews of staff and volunteers chipped out 12ha of buffel over a year at a cost of $50 000 (Puckney and Albrecht, 2004).

In Queensland reserves it could be used to limit expansion by controlling small outbreaks in areas not otherwise invaded by buffel grass. Follow-up would be essential.

MECHANICAL CONTROL

Repeated cultivation can eventually control a buffel grass infestation (Tu, 2002) but is not applicable on reserves except for fire control lines, in combination with spraying, or specific management purposes such as the maintenance of 'feed strips' for the bridled nailtail wallaby on Taunton National Park.

Slashing may be a useful tool in small strategic areas as a means of reducing fuel loads but it is not an effective control technique on its own. Slashing induces buffel grass to flower and set seed while the plants are very short (Melzer, 2001). Slashing followed by spot spraying (including follow-up spraying) was found to be very effective for the restoration of native vegetation in trial plots in central Australia (Schlesinger et al., 2013).

HERBICIDE CONTROL

Herbicide control is suitable for most reserves as part of an integrated control program but resourcing is usually prohibitive for large areas and some herbicides have the further disadvantage of non-target impacts. It is ideal for tackling isolated patches of buffel grass and infestations along roadsides and fire control lines. A combination of manual or mechanical control and/or burning and herbicides can be effective.

Trials using Roundup Biactive are underway on Epping Forest and Taunton National Parks. The latter trials are examining the recovery/response of buffel grass and other species over time with one to several treatments (Melzer and Dinwoodie, 2012). Earlier trials at Taunton National Park demonstrated the value – in terms of species richness, including of fodder species of the bridled nailtail wallaby – of herbicide control of buffel grass in small plots (Melzer et al., 2010, Melzer et al., 2015). Flupropanate has been trialled in liquid form on Mazeppa National Park by the Department of Agriculture, Forestry and Fisheries. Whilst initial results were promising buffel grass has subsequently recovered dense cover. Flupropanate has the advantage of being residual and, depending on the application rate, selective (W. Vogler pers. com). A granular form is available and is being applied from the air to control rat's tail grass (W. Vogler pers. com.). Flupropanate is not currently registered for buffel grass but may hold promise in the future including for aerial application over relatively large and/or inaccessible areas including wooded areas with a sufficiently sparse canopy to allow penetration. Verdict, another grass selective herbicide has been trialled at Uluru National Park in combination with burning to good effect (K. Bennison pers.com).

Timing is critical – effective herbicide control, at least with foliar sprays, is only achieved if the buffel grass is actively growing and not showing any sign of senescence; follow-up is essential (Dixon et al., 2002; CRC Weed Management, 2008; Biosecurity SA, 2012).

PLANNED BURNING

Burning is a widely used and important 'tool' in conservation reserves including for reducing fuel loads, promoting native species regeneration, and control of some weed species (e.g. *Lantana camara*). It has the advantage of being relatively cost effective for management on a broad scale.

Unfortunately, the overwhelming experience of reserve managers and the then Queensland Department of Primary Industries and Forestry (QDPIF) staff (Melzer, 2001, 2003, 2005), the scientific community (Low, 1997 cited in Franks 2000; Franks et al., 2000; Tu, 2002; Butler & Fairfax, 2003; Miller, 2003; Desert Knowledge CRC, 2005; Smyth et al., 2009; Marshall et al., 2012) and pastoralists (Melzer, 2001, 2003) is that buffel grass thrives with fire.

Fire can cause mortality of some tussocks, particularly smaller tussocks, within a buffel grass sward – the greatest mortality being associated with higher intensity fires (Jackson, 2004), and clearly, burning can be used to reduce the fuel load. Fuel reduction is however short-lived because of the ability of buffel grass to rapidly regenerate vegetatively and produce large quantities of seed. While seedlings appear only to establish readily where there is bare ground (McIvor, 2003), the latter can be expected to be available after a fire, including one of low intensity. The availability of moisture (often a pre-requisite for a planned burn in order to minimise intensity and damage to standing vegetation, promote patchiness and minimise loss of critical habitat features such as fallen logs and hollow-bearing trees) will promote germination. Data from Moorrinya National Park indicate that buffel grass returned to approximately two thirds of its pre-burn cover in one year (P.Williams pers. comm. in Melzer, 2005). In Marengo Section of Carnarvon National Park the buffel grass-dominated fuel loads in plots adjacent to, and within, brigalow were greater than 10

t/ha and 5-10t/ha respectively, one year after a back burn (Brecknell & Tangey, 2012). Given the typically rapid rate of regeneration of buffel grass it would not be unreasonable to expect, for the purpose of reducing fire hazard, to require at least a biannual fire and probably an annual burn in some areas, particularly given an average or above average season.

Minimising fire damage to ecosystems invaded by buffel grass is problematic. For example, minimising damage to bridled nailtail wallaby habitat in Taunton National Park requires that planned burns be excluded from fire-sensitive communities and are of sufficiently low intensity not to destroy critical habitat features (e.g. hollow logs and low shrubs) in fire-adapted communities. Because of the biomass that buffel grass produces it has the potential to result in an intense fire that causes extensive canopy scorch. On the other hand it rapidly 'greens up' after rain and tends to retain moisture in the stems for a much longer period than native species (P. Lawless-Pyne pers. comm. in Melzer, 2005). At Taunton National Park it has been observed that the time between buffel grass being fully cured at the end of the dry season to being unburnable because it has 'greened up' can be less than a fortnight. The 'window' in which to burn buffel at low intensity is therefore often very narrow and the risk of not achieving a low intensity burn is high.

Unfortunately, even low intensity burns on Taunton National Park have been found to result in increased buffel grass dominance and distribution. Low intensity planned burns were conducted adjacent to brigalow scrub to create a protective buffer against wildfires. The fire trickled through the leaf litter in the scrub margins and caused very little to no canopy scorch. However, with the removal of the litter layer buffel grass was able to establish in the scrub margins and a much greater fuel load developed than was present prior to the burns (G. Porter pers. comm. in Melzer, 2005). A similar result was observed after a low intensity burn in the south-west corner of the reserve. It was conducted after good rain and was extinguished by a heavy storm. Within a few weeks the buffel grass 'front' was observed to perfectly align with that of the burn edge (J. Wyland pers. comm. in Melzer, 2008).

Burning, in combination with control options such as herbicide can be used in fire-adapted communities to control new and isolated outbreaks and reduce infestations (and fuel loads) in strategic areas (e.g. boundaries, internal control lines, buffers adjacent to fire sensitive ecosystems).

It is imperative, when burning native vegetation where buffel grass is absent but a source of seed is nearby, to monitor the area after the burn for buffel grass emergents (at least until the litter layer and ground stratum vegetation have re-established), and to control them prior to seed set.

REGROWTH ENHANCEMENT (PROMOTING RAPID WOODY THICKENING)

Woody thickening is evident in some ecosystems under some land management practices including heavy grazing. It may be possible, and beneficial in some circumstances, to promote woody thickening to help minimise the risk of buffel grass invasion or to shade out established buffel. Some species, most notably *Acacia harpophylla* (brigalow), sucker in response to root disturbance and it may be feasible to use this characteristic to thicken the edge of a remnant or hasten the thickening of a patch of regrowth. The effective application of root disturbance for this purpose has not yet been demonstrated (Melzer et al., 2010). The pros and cons of employing the level of disturbance required to achieve rapid thickening would need to be considered carefully.

CONTROL OPTION – STOCK GRAZING

Australian ecosystems evolved in the absence of grazing by domestic stock and it is therefore appropriate in most circumstances to exclude stock grazing when an area is set aside for the purpose of nature conservation. The benefits of doing so are well documented, including in Queensland (Williams and Collins, 2004; Legge et al., 2011; Kutt and Gordon, 2012; Kutt et al., 2012). The impacts of grazing are well known and include trampling and compaction, erosion, selective grazing resulting in changes in plant species composition including declines in palatable natives, modification of vegetation structure, nutrient enhancement, promotion of weeds, loss or modification of fauna habitat with flow-on effects for the fauna dependent on it (Lunt et al., 2007; Eyre et al., 2009; Kutt and Fisher, 2011). Some native flora and fauna will be enhanced in grazed landscapes but are already well catered for in the majority of Queensland given the large proportion of the state under grazing.

When considering the option of using stock grazing as a management tool on a conservation reserve for

the purpose of achieving biodiversity outcomes the decision must be based on the known and potential present and future impacts on current condition and future trends (Lunt et al., 2007). It must enable a conservation outcome to be achieved that cannot be achieved by other means and in doing so the benefits must outweigh the negative impacts.

The type of grazing (e.g. pulse versus continuous) and grazer (e.g. cattle versus sheep) will have a significant influence on outcomes and impacts and must therefore be considered in detail if the use of stock grazing is being contemplated as a management 'tool' on a conservation reserve. The infrastructure required for grazing, its impact on the environment and ongoing maintenance requirements must also be carefully considered. None of these is discussed in this document as they must be considered in the context of the specific situation including desired outcomes and associated risks.

A DECISION FRAMEWORK

Although Australian ecosystems have no evolutionary exposure to livestock in the usual sense (i.e. they weren't grazed by livestock prior to European settlement) the current condition of those areas with a long history of grazing since European settlement, particularly of heavy grazing, is shaped by that grazing (and associated practices). They often contain, or are dominated by, introduced species that evolved under heavy grazing in other continents (Lunt et al., 2007). It is these areas where stock grazing may be an appropriate management tool – providing that the conservation outcomes being sought cannot be achieved by other means and the benefits outweigh the impacts. In contrast, areas that have had little or no exposure to stock grazing are likely to contain grazing sensitive species that will be poorly represented elsewhere in the landscape (Lunt et al., 2007). Grazing is far less likely to be an appropriate conservation management tool in such areas.

Lunt et al., (2007) have developed the first conceptual framework (FIG. 1) to predict the effects of stock grazing (or its removal) on the conservation values of native vegetation in natural ecosystems in Australia. Their work makes it clear that stock grazing is likely to be detrimental to biodiversity conservation in many circumstances. The framework and, in particular, the discussion of the parameters incorporated in it are invaluable and should be read by conservation managers considering grazing as a management tool.

It does not however, effectively account for a scenario where buffel grass (or indeed any other high biomass grass) is abundant (frequently dominant) over large areas. In the latter scenario the most applicable paths on FIG. 1 lead to: *'Explanation E' - grazing reduces biomass but there is no obvious benefit to native plants* because the dominant species in the ground stratum increases with grazing, and so the *'Potential Outcome' is negative*; and *'Explanation J' - Grazing has substantial negative impacts on landscape processes*. This does not however, account for the fundamental structural and compositional changes to an ecosystem that can occur as a result of invasion by a high biomass grass and the associated increases in fire frequency, intensity and flame height. A framework specific to the impacts of buffel grass on conservation reserves in Queensland is provided in FIG. 2 and is explained below.

Grazing will not control buffel grass, especially if it is not used as part of an integrated control program. It can in fact be expected to promote buffel grass invasion and spread through: seed dispersal on hooves and hair; soil disturbance; and the creation of bare areas. Observations by Franks (2002) indicated that buffel grass seeds germinate with even minor soil disturbance including the surface soil being broken by stock movement. This was borne out by a study in remnant poplar box woodlands in the Brigalow Belt Bioregion which demonstrated that an increase in grazing pressure corresponded to an increase in the cover of buffel grass (Eyre et al., 2009). Buffel grass seedlings are able to establish in bare areas irrespective of whether these occur naturally or as a result of over-grazing or other disturbances so where the aim is to discourage its spread it is critical to maintain competition from native vegetation (McIvor, 2003) and minimise disturbance. Therefore stock (including stray stock) should be excluded from areas where buffel grass is absent, occurs as scattered plants or in relatively small patches (e.g. along roadsides) - Scenarios 1a and 1b in FIG 2. Other control options should be used; control should be implemented as soon as possible and with the intent of eradication or at least containment; and ecosystems should be managed to maximise ground cover to minimise the risk of buffel grass invasion and spread. Planned burning should be conducted in a manner that ensures rapid recovery of the ground layer.

In situations where buffel grass is established, widespread and abundant (Scenarios 2a and 2b in FIG. 2) the focus is on reducing its impact on biodiversity values; if fire-sensitive ecosystems are involved

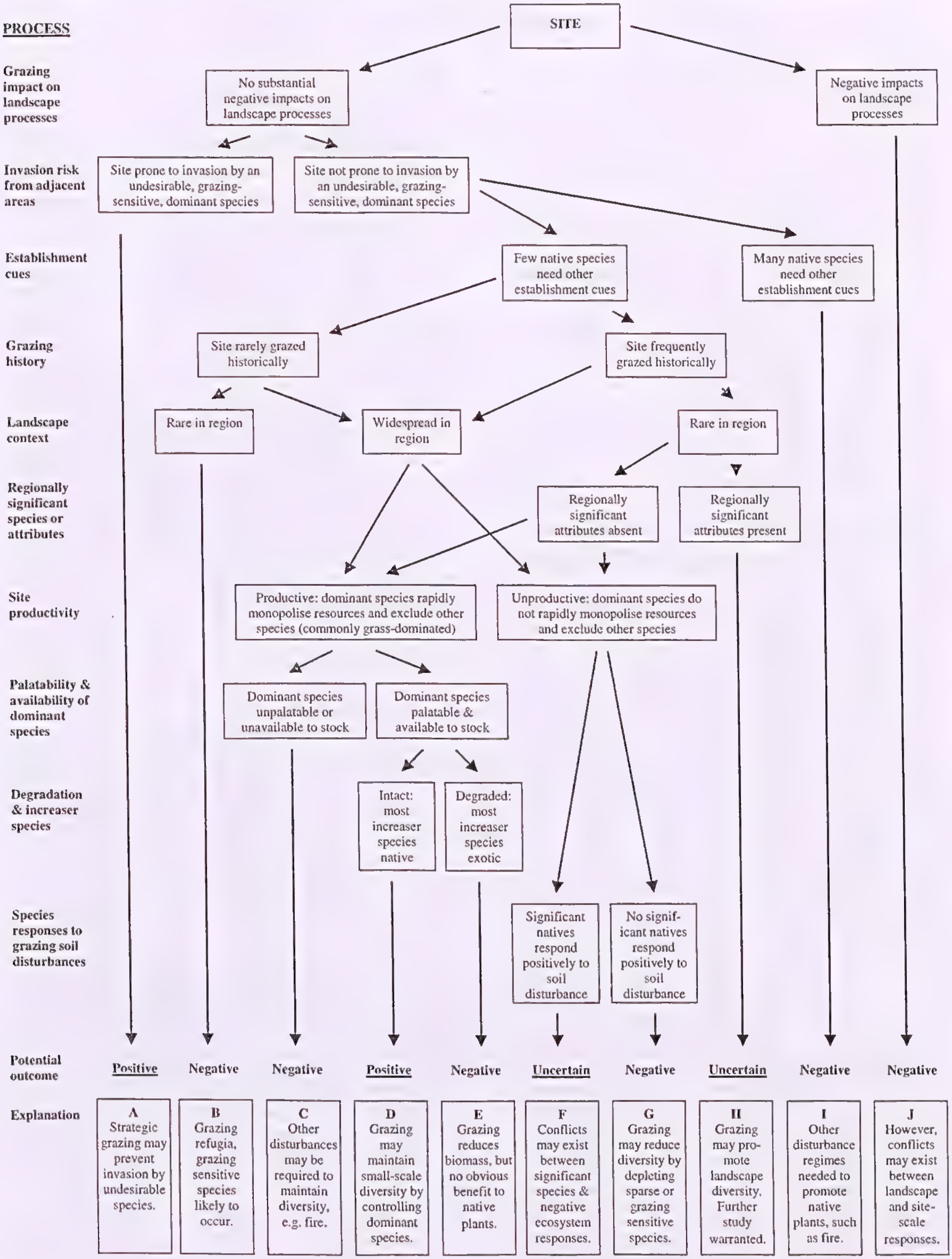

FIG. 1 A decision tree to help predict the effects of stock grazing and grazing exclusion on conservation values in natural ecosystems in Australia (from Lunt et al., 2007).

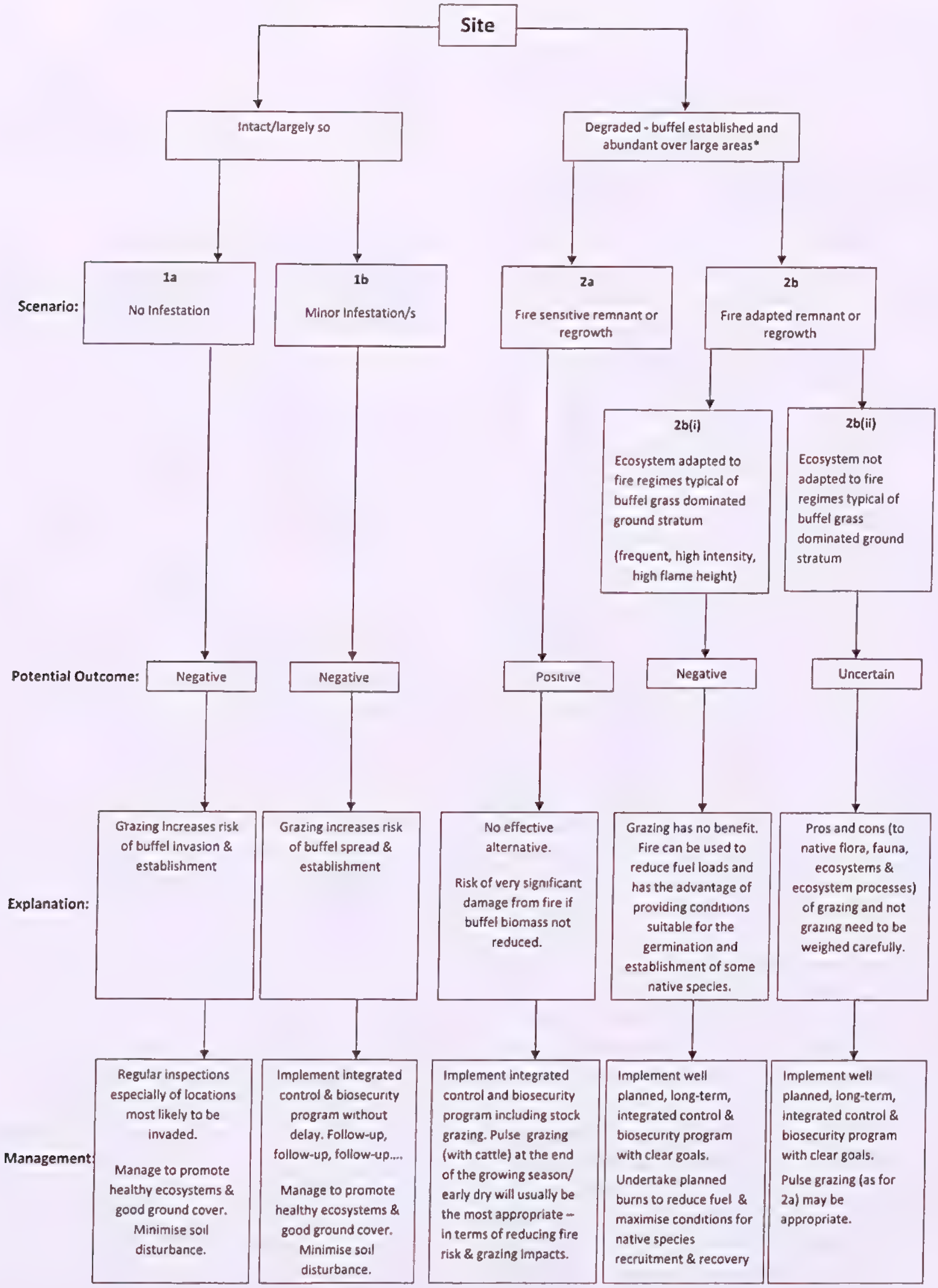

FIG 2. A decision tree to help determine when stock grazing may be an appropriate management tool for reducing the impacts of buffel grass of natural values on conservation estate.

*typically hundreds of hectares in which buffel grass (± other exotic high biomass grasses) has a mean cover of >30% (frequently much great) and/or is of sufficient density to carry an intense fire.

this typically means preventing long-term damage or perhaps permanent destruction. Friedel et al., (2008), in their review of the outcomes of stakeholder workshops aimed at quantifying costs and benefits of buffel grass, noted that for environmental reserves 'tools for suppression were limited to grazing where it was permissible and in some instances fire, followed by grazing or herbicides.' Participants at a workshop on buffel grass management in reserves (Melzer, 2001) agreed that grazing was the only management tool available for buffel grass suppression in many situations and in particular where infestations are extensive and altered fire regimes (associated with the higher fuel loads created by buffel grass) threaten fire-sensitive plant communities. In a media release (Desert Knowledge CRC, 2005) Dr Margaret Friedel from CSIRO stated: "Just about the only thing that keeps it (buffel) in check is grazing – and the time may come when we have to consider this as one strategy for protecting parts of national parks and nature reserves which have been invaded by buffel." Mr John Chamberlain (then QDPIF) notes (pers. comm. in Melzer, 2003) that "if buffel has a weakness, and it has very few, it is consistent grazing at the end of its growing season when it is storing reserves. Consistent grazing at that time will, in the long-term, hasten rundown and grazing re-sprouted buffel following fire will enhance the stress on the buffel plants even further." In an overseas study, continual heavy grazing of buffel grass was found to lead to a shallower root system (Chaieb et al., 1996 cited in Tu, 2002) which in turn may render it more susceptible to drought.

In Scenario 2a the outcome from grazing is overwhelmingly positive, simply because the risk of significant long-term or permanent damage to the ecosystem from fire is high. Where fire-sensitive ecosystems have been degraded such that their density and canopy cover is no longer sufficient to suppress buffel grass the aim would be to promote woody regrowth by excluding fire and shifting the competitive advantage from the grass to woody species. The latter can be achieved with grazing (Dr R. Johnson pers. comm.) and may be best achieved by heavy grazing (A. Clarke pers. comm.). Grazing is being used for this purpose on Albinia Regional Park (Melzer A., 2011; Melzer R., 2011; Melzer in prep.) and Taunton National Park - Special Management Area (Scientific) (Melzer, 2012). At present there is no other cost effective alternative to protect or recover these ecosystems, although the means to control buffel grass with herbicide over large areas is being explored (Melzer and Dinwoodie, 2012) and may become viable in the future. In Scenario 2a, grazing should be part of a long-term integrated control plan that would typically include herbicide control (e.g. along roadsides to minimise further spread). Clearly documented objectives, performance criteria and associated monitoring and review must be integral to the program. Managers must always be alert to changing circumstances and emerging control options that would enable grazing to be removed without jeopardising the ecosystem.

In the case of a fire-adapted remnant or regrowth ecosystem in which buffel grass is established and abundant over substantial areas (Scenario 2b) the potential outcome from grazing is more ambiguous. If an ecosystem is adapted to a fire regime similar to that produced by buffel grass (Scenario 2bi) then grazing is not beneficial (*Outcome = Negative*, FIG. 2). In this circumstance (e.g. grasslands), fire can be used to reduce the biomass, has the added advantage of triggering germination in those species requiring the conditions produced by a burn, and does not have the disadvantages of grazing – that of physical soil disturbance and transport of seed on hair/hooves. On the other hand, if a fire-adapted ecosystem is not adapted to frequent or intense fire, or the flame height produced by buffel grass (Scenario 2bii), the outcome is *Uncertain* and will in large part depend on the ecosystem (including flora and fauna assemblages) in question. In these circumstances the positive benefits (e.g. reduction in fuel loads and associated reduction in risk of damaging wildfire) and negative impacts of different grazing regimes (e.g. pulse, continuous), including those related to the structure and composition of the vegetation community, and the fauna habitat and fauna species, must be considered carefully on a case by case basis. Expert advice must be sought.

CONCLUSION

There is often a perception that conservation reserves, and in particular national parks, are natural, perhaps even pristine, 'islands' in an otherwise human-altered landscape. They are indeed places of great natural, cultural and scenic value but they are not isolated from external influences. Many sit within anthropogenic landscapes dominated by grazing-adapted pastures and rangelands, and it is to be expected that there will be some negative environmental pressures as a consequence. Invasive pest species, for example, do not respect boundaries.

Even large, relatively remote parks have been invaded by buffel grass and in some cases significant degradation of ecosystems, particularly fire-sensitive ecosystems, has occurred as a result.

It is also common for conservation reserves acquired in more recent times to be ex-grazing properties, modified to some extent by clearing, the accidental or intentional introduction of exotic pasture species, and grazing practices generally. These grazing properties had biodiversity values sufficient to warrant their acquisition for the conservation estate but it will sometimes be impossible to manage them to maintain or achieve biodiversity outcomes in the same way as those that have not had a long history as a grazing enterprise. This is certainly the case when high biomass pasture grasses, such as buffel grass, and fire-sensitive ecosystems are present.

Whether a conservation reserve contains buffel grass as a result of a long history of commercial grazing or as a result of accidental invasion, it will sometimes be necessary to employ 'novel' approaches, such as stock grazing, to ensure the protection or recovery of natural values. Stock grazing must however, only be considered for use on a conservation reserve when there is no other effective means to minimise the impacts of buffel grass on natural values; and the conservation outcomes achieved by stock grazing far outweigh any negative impacts. This is most likely to be the case when buffel is widespread and abundant within a fire-sensitive ecosystem. The grazing must be undertaken as part of an integrated control strategy with explicit outcomes and performance measures that can be evaluated over time. Because the purpose of the grazing is not about a commercial goal it is imperative that the stock owner/manager is fully aware of, and dedicated to, pursuing the conservation outcome.

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LITERATURE CITED

ARRIAGA L., CASTELLANOS A.E., MORENO E. & ALARCON J. 2004. Potential ecological distribution of alien invasive species and risk assessment: a case study of buffel grass in arid regions of Mexico. Conservation Biology 18: 1504-1514.

ASDMSV 2008. Buffelgrass Information Center – website maintained by Arizona-Sonora Desert Museum Staff and Volunteers. http://www.buffelgrass.org/biological.php

BEST R.A. 1988. The effect of introduced buffel grass (*Cenchrus ciliaris* L., Poaceae) on the diversity and abundance of invertebrates in semi-arid central Australia. Honours Thesis, Northern Territory University.

BIOSECURITY SA 2012. South Australia Buffel Grass Strategic Plan 2012-2017. A plan to reduce the weed threat of buffel grass in South Australia. Government of South Australia.

BRECKNELL T. & TANGEY B. 2012. Vegetation fire monitoring, Carnarvon National Park - Marengo Section. Internal Report, Queensland Parks and Wildlife Service.

BUTLER D.W. & FAIRFAX R.J. 2003. Buffel grass and fire in a gidgee and brigalow woodland: a case study from central Queensland. Ecological Management and Restoration 4 (2): 120-125.

CHAIEB M., HENCHI B. & BOUKHRIS M. 1996. Impact of clipping on root systems of three grass species in Tunisia. Journal of Range Management 49: 336-339.

CRC WEED MANAGEMENT 2008. Weed Management Guide – buffel grass. Cooperative Research Centre Weed Management.

CSIRO undated. Buffel Distribution. Note produced by CSIRO Sustainable Ecosystems.

COX J.R., MARTIN-R J.H., IBARRA-F F.A., FOURIE J.H., RETHMAN J.F.G. & WILCOX D.G. 1988. The influence of climate and soils on the distribution of four African grasses. Journal of Range Management 41: 127-139.

DE LISLE D.G. 1963. Taxonomy and distribution of the genus *Cenchrus*. Iowa State Journal of Science 37: 259-351.

DESERT KNOWLEDGE COOPERATIVE RESEARCH CENTRE 2005. Buffel in landscape dilemma. Media Release 12 Sept. 2005.

DIXON I.R., DIXON K.W. & BARRETT M. 2002. Eradication of buffel grass (*Cenchrus ciliaris*) on Airlie Island, Pilbara Coast, Western Australia. In Veitch, C.R. & Clout, M.N. (eds), Turning the tide: the eradication of invasive species. IUCN SSC Invasive Species Specialist Group. IUCN, Gland, Switzerland and Cambridge, UK.

EYRE T.J., WANG J., VENZ M.F., CHILCOTT C. & WHISH G. 2009. Buffel grass in Queensland's semi-arid woodlands: response to local and landscape scale variables, and relationship with grass, forb and reptile species. The Rangeland Journal 31: 293-305.

FAIRFAX R.J. & FENSHAM R.J. 2000. The effect of exotic pasture development on floristic diversity in central Queensland, Australia. Biological Conservation 94: 11-21.

FENSHAM R.J., DONALD S. & DWYER J.M. 2013. Propagule pressure, not fire or cattle grazing, promotes invasion of buffel grass *Cenchrus ciliaris*. Journal of Applied Ecology 50:138-146.

FENSHAM R.J., WANG J., & KILGOUR C. 2015. The relative impacts of grazing, fire and invasion by buffel grass (*Cenchrus ciliaris*) on the floristic composition of a rangeland savannah ecosystem. The Rangeland Journal 37: 227-237.

FRANKS A. 2000. The ecological consequences of buffel grass *Cenchrus ciliaris* establishment within remnant vegetation of Queensland. Pacific Conservation Biology 8: 99-107.

FRANKS A., BUTLER D. & FAIRFAX R. 2000. A weed by any other name. Wildlife Australia 37: 24.

FRIEDEL M., PUCKEY H., O'MALLEY C., WAYCOTT M., SMYTH A. & MILLER G. 2006. Buffel grass: both friend and foe. An evaluation of the advantages and disadvantages of buffel grass use, and recommendations for future research. A report to the Desert Knowledge Cooperative Research Centre.

FRIEDEL M., BASTIN G., BROCK C., BUTLER D., CLARKE A., EYRE T., FOX J., GRICE T., VAN LEEUWEN S., PITT J., PUCKEY H. & SMYTH A. 2007. Developing a research agenda for the distribution and rate of spread of buffel grass (*Cenchrus ciliaris*) and identification of landscapes and biodiversity assets at most risk from invasion. A report to the Department of the Environment and Water Resources, Dec. 2007.

FRIEDEL M., MARSHALL N., VAN KLINKEN R.D. & GRICE T. 2008. Quantifying costs and benefits of buffel grass. A report on the outcomes of stakeholder workshops and surveys on issues relating to the sustainable management of buffel grass for production and conservation. CSIRO.

GRAHAM G. 2001. Pasture species in Central Queensland – buffel grass. DPI Note. Qld Government.

GREENFIELD B. 2007. SA Arid Lands buffel grass management plan, Draft. South Australian Arid Lands Natural Resource Management Board.

HANNAH D. & THURGATE N. 2001. Lands of strips and patches. Wildlife Australia 41: 38-39.

HANNAH D., WOINARSKI J.C.Z., CATTERALL C.P., MCCOSKER J.C., THURGATE N.Y. & RENSHAM R.J. 2007. Impacts of clearing , fragmentation and disturbance on the bird fauna of eucalypt savanna woodlands in central Queensland, Australia. Austral Ecology 32: 261-276.

HUMPRHIES L.R. 1967. Buffel grass (*Cenchrus ciliaris*) in Australia. Tropical Grasslands 1:123-134.

HUMPHRIES S.E. 1993. Environmental impact of weeds. In: Proc. II. 10th Australian Weeds Conference and 14th Asian Pacific Weed Science Society Conference. The Weed Society of Queensland, Brisbane. Pp. 1-11.

HUMPHRIES S.E., GROVES R.H. & MITCHELL D.S. (eds) 1991. Plant invasions of Australian ecosystems: a status review and management directions. Kowari 2. A report to Australian National Parks and Wildlife Service funded by the Endangered Species Program and the CSIRO.

JACKSON J. 2004. Impacts and management of *Cenchrus ciliaris* (buffel grass) as an invasive species in northern Queensland. PhD Thesis, James Cook University.

JACKSON J. 2005. Is there a relationship between herbaceous species richness and buffel grass (*Cenchrus ciliaris*)? Austral Ecology 30: 505-517.

JOHNSON B. 2006. Buffel grass in south Queensland. DPI&F Note. Qld Govt.

KEETCH R.I. 1981. Rangeland rehabilitation in central Australia. Alice Springs, Conservation Commission of the Northern Territory.

KUTT, A. S. & FISHER A. 2011. Increased grazing and dominance of an exotic pasture (*Bothriochloa pertusa*) affects vertebrate fauna species composition, abundance and habitat in savanna woodland. The Rangeland Journal 33:49-58.

KUTT, A. S. & GORDON I.J. 2012. Variation in terrestrial mammal abundance on pastoral and conservation land tenures in north-eastern Australian tropical savannas. Animal Conservation 15:416-425.

KUTT, A. S., VANDERDUYS E.P., PERRY J.J., PERKINS G.C., KEMP J.E., BATEMAN B.L., KANOWSKI J. & JENSEN R. 2012. Signals of change in tropical savanna woodland vertebrate fauna five years after cessation of livestock grazing. Wildlife Research 39:386-396.

LAWSON B.E., BRYANT M.J. & FRANKS A.J. 2004. Assessing the potential distribution of buffel grass (*Cenchrus ciliaris* L.) in Australia using a climate-soil model. Plant Protection Quarterly 19 (4): 155-163.

LATZ P. 1991. Buffel and couch grass in central Australian creeks and rivers. Newsletter of the Central Australian Conservation Council Inc. April 5. Central Australian Conservation Council syn. Arid Lands Environment Centre, Alice Springs.

LEGGE S., KENNEDY M.S., LLOYD R., S. A. MURPHY S.A. & FISHER A. 2011. Rapid recovery of mammal fauna in the central Kimberley, northern Australia, following the removal of introduced herbivores. Austral Ecology 36:791-799.

LOW T. 1997. Tropical pasture plants as weeds. Tropical Grasslands 31: 337-343.

LUDWIG J.A., EAGER R.W., LIEDLOFF A.C, MCCOSKER J.C., HANNAH D., THURGATE N.Y., WOINARSKI J.C.Z. & CATTERALL C.P. 2000. Clearing and grazing impacts on vegetation patch structures and fauna counts in eucalypt woodland, Central Queensland. Pacific Conservation Biology 6: 254-72.

LUNT I.D., ELDRIDGE D.J., MORGAN J.W. & BRADD WITT G. 2007. A framework to predict the effects of livestock grazing and grazing exclusion on conservation values in natural ecosystems in Australia.

MARSHALL V.M., LEWIS M.M. & OSTENDORF B. 2012. Buffel grass (*Cenchrus ciliaris*) as an invader and threat to biodiversity in arid environments: a review. Journal of Arid Environments 78: 1-12.

MCIVOR J.G. 2003. Competition affects survival and growth of buffel grass seedlings – is buffel grass a coloniser or an invader? Tropical Grasslands 37: 176-181.

MELZER A. 2011. Managing buffel grass to achieve conservation outcomes - Albinia progress report 2010/2011. CQUniversity report for Queensland Parks and Wildlife Service.

MELZER A. 2013. Managing Buffel Grass to achieve conservation outcomes in the Central Highland Native Grasslands and associated Brigalow dominated ecosystems. Supplementary Report: Results of winter 2013 monitoring of the Taunton spray plots. Report to Fitzroy Basin Association.

MELZER A. (in prep.) Reducing fire fuel loads within fire sensitive regrowth *Acacia harpophylla* shrublands.

MELZER A. & DINWOODIE A. 2012. Facilitated regeneration of brigalow ecosystems at Taunton National Park (Scientific). Report 5: Broad area spray trials - site establishment. Report to Queensland Parks and Wildlife Service and Fitzroy Basin Association.

MELZER A., DINWOODIE A. & MELZER R. 2010. Facilitated regeneration of brigalow ecosystems at Taunton National Park (Scientific). Report 3: Vegetative response. CQUniversity report to Queensland Parks and Wildlife Service.

MELZER A., MELZER R., DINWOODIE A. & BEARD D. 2015. Recovery of herbaceous species richness following herbicide treatment of *Cenchrus ciliaris* (buffel grass) - a pilot study in *Onychogalea fraenata* (bridled nailtail wallaby) habitat restoration. Proceedings of the Royal Society of Queensland 119: 7-20.

MELZER R. (ed.) 2001. Buffel grass management in reserves – workshop 1. Summary of a workshop held 22 Feb. 2001 as part of: Remnant vegetation in the Brigalow Belt – management and conservation. A symposium presented by Central Queensland University's Centre for Environmental Management in association with QPWS (Central Region) and the Centre for Conservation Biology, University of Queensland. 20-22 February 2001, Central Queensland University Rockhampton Campus.

MELZER R. (ed.) 2003. Transcript: Natural Resource

Management Workshop – Nairana.19-21 August, 2003. Technical Services Unit, Parks Services, Central Region, QPWS.

MELZER R. 2005. Document past experience with burning buffel in gidgee communities and in particular assess whether low intensity burns can be used to manage gidgee remnants or regrowth that have been invaded by buffel grass – action arising from QPWS Director's meeting, 26 October 2004. Internal report, Technical Support Unit, Parks Services, Central Region, QPWS.

MELZER R. 2006. Evaluating the effectiveness of cattle grazing as a management tool to reduce fuel loads and thereby facilitate the regeneration of a fire-sensitive regrowth community in Albinia Conservation Park. Pest Arrest in CQ Project Brief. Internal Report, Technical Support Unit, Parks Services, QPWS.

MELZER R. (ed.) 2008. Transcript of a workshop on the management of Taunton National Park (Sci) and its bridled nailtail wallaby population. Workshop held at Taunton National Park (Scientific) on 12-14 August, 2008. Internal report, Ecological Assessment Unit, Conservation Management Branch, QPWS.

MELZER R. 2011. Evaluating the effectiveness of cattle grazing as a management tool to reduce fuel loads and thereby facilitate the regeneration of a fire-sensitive regrowth community in Albinia Conservation Park. Project Brief vers. 3. Queensland Parks and Wildlife Service.

MELZER R. 2012. Using cattle grazing as a management tool to protect, and promote the recovery of, habitat for the bridled nail-tail wallaby at Taunton National Park (Scientific). Project Brief. Queensland Parks and Wildlife Service.

MELZER R. & PORTER G. 2002. Guidelines for the management of buffel grass on conservation reserves. Internal report, Natural Resource Management Unit, Central Region, QPWS.

MILLER G. 2003. Ecological impacts of buffel grass (*Cenchrus ciliaris* L.) invasion in central Australia – does field evidence support a fire-invasion feedback? Honours thesis, University of New South Wales.

MILLER G., FRIEDEL M, ADAM P. & CHEWINGS V. 2010. Ecological impacts of buffel grass (*Cenchrus ciliaris* L.) invasion in central Australia – does field evidence support a fire-invasion feedback? The Rangeland Journal 32: 353-365.

MULLER P. 2000. Soil properties of the buffel grass pasture lands. Queensland Beef Industry Institute Buffel Grass Workshop. Theodore 21-23 February 2000.

NEW SOUTH WALES DEPARTMENT OF PRIMARY INDUSTRIES 2004. Buffel grass. AgnoteDPI-289. Available at: http://www.dpi.nsw.gov.au/agriculture/pastures/pastures-and-rangelands/species-varieties/factsheets/buffel-grass (accessed 23 April 2014).

NEW SOUTH WALES GOVERNMENT 2011. Case study 4: Threatened species management on Oolambeyan National Park. Office of Environment and Heritage. Available at: http://www.environment.nsw.gov.au/sop04/sop04cs4.htm (accessed 30 April 2014).

NEW SOUTH WALES GOVERNMENT 2012. Draft Plan of Management Oolambeyan National Park. Office of Environment and Heritage, National Parks and Wildlife Service.

NURDIN & FULBRIGHT T.E. 1990. Germination of two legumes in leachate from introduced grasses. Journal of Range management 43(5): 466-467.

PARKER D.G. & OLIVER D.L. 2007. Plains-wanderer habitat management guide. A photographic guide for visually assessing the grassland structure of plains-wanderer habitat. 3rd edition. Department of Environment and Climate Change and Murray Catchment Management Authority.

PUCKEY H. & ALBRECHT D. 2004. Buffel grass (*Cenchrus ciliaris* L.) presenting the arid Northern Territory experience to our South Australian neighbours. Plant Protection Quarterly 19 (2): 69-72.

RUTMAN S. 1998. At what cost? Deciding whether to control exotic plants. Natural Resource Year in Review – 1998, National Park Service, US Dept of the Interior, Publ. D-1346.

SCHLESINGER C., WHITE S. & MULDOON S. 2013. Spatial pattern and severity of fire in areas with and without buffel grass (*Cenchrus ciliaris*) and effects on native vegetation in central Australia. Austral Ecology 38(7): 831-840.

SMYTH A., FRIEDEL M. & O'MALLEY C. 2009. The influence of buffel grass (*Cenchrus ciliaris*) on biodiversity in an arid Australian landscape. The Rangeland Journal 31: 307-320.

TIX D. 2000. *Cenchrus ciliaris* invasion and control in southwestern U.S. grasslands and shrublands. Restoration and Reclamation Review. Student on-line journal 6(1).

TU M. 2002. Element stewardship abstract for *Cenchrus ciliaris* L. The Nature Conservancy. http://tncweeds.ucdavis.edu/esadocs/documnts/cenccil.html

WILLIAMS P. & COLLINS E. 2008. Results

of vegetation monitoring on Moorrinya National Park between 1997 and 2008. Internal Report. Queensland Parks and Wildlife Service, Townsville.

WINKWORTH R.E. 1971. Longevity of buffel grass seed sown in an arid Australian Range. Journal of Range Management 24: 141-145.

PERSONAL COMMUNICATIONS

Mr Daniel Beard (then Ranger, Rockhampton Management Unit, Capricornia Region, QPWS).

Ms Kerrie Bennison (Manager Natural and Cultural Resources, Uluru-Kata Tjuta National Park, Parks Australia).

Mr John Chamberlain (then Grazing Lands, Regional Delivery, Department of Primary Industries and Fisheries).

Mr Adam Clarke (Grazier, Member of Wildlife Preservation Society of Queensland).

Dr Robert Johnson (late) (Brigalow expert; previously OIC Brigalow Research Station and Director Qld Herbarium).

Mr Neil Kershaw (then Regional Manager, Central Coast Region, QPWS).

Mr Paul Lawless-Pyne (Ranger, Special Projects, Capricornia Region, QPWS).

Mr Gary Porter (then Senior Technical Officer, Parks Services, Central Region, QPWS).

Mr Peter Tierney (then bridled nailtail wallaby researcher, QPWS; currently Operations Manager Sunshine Coast Burnett Region).

Mr Wayne Vogler (Senior Weed Scientist, Biosecurity Qld, Department of Agriculture, Forestry and Fisheries).

Dr Paul Williams (then Senior Conservation Officer, Parks Services, Northern Region, QPWS).

Mr John Wyland (then Ranger, Taunton National Park (Scientific), Capricornia Region, QPWS).

AUTHOR PROFILE

Dr Rhonda Melzer leads the Ecological Assessment Unit in Queensland Parks and Wildlife Service. She is working with colleagues inside and outside the Service to develop practical methods for maintaining conservation outcomes in buffel grass dominated landscapes.

AN INVESTIGATION OF ENVIRONMENTAL CONDITIONS EXPERIENCED DURING THE LIFE OF HIGH-VALUE WOOD COMPONENTS AND PRODUCTS

HOPEWELL, G.P.

THESIS ABSTRACT

Australian forest industries have a long history of export trade of a wide range of products from woodchips (for paper manufacturing), sandalwood (essential oils, carving and incense) to high value musical instruments, flooring and outdoor furniture. For the high value group, fluctuating environmental conditions brought on by changes in temperature and relative humidity, can lead to performance problems due to consequential swelling, shrinkage and/or distortion of the wood elements.

A survey determined the types of value-added products exported, including species and dimensions packaging used and export markets. Data loggers were installed with shipments to monitor temperature and relative humidity conditions. These data were converted to timber equilibrium moisture content values to provide an indication of the environment that the wood elements would be acclimatising to.

The results of the initial survey indicated that primary high value wood export products included guitars, flooring, decking and outdoor furniture. The destination markets were mainly located in the northern hemisphere, particularly the United States of America, China, Hong Kong, Europe (including the United Kingdom), Japan, Korea and the Middle East. Other regions importing Australian-made wooden articles were south-east Asia, New Zealand and South Africa.

Different timber species have differing rates of swelling and shrinkage, so the types of timber were also recorded during the survey. Results from this work determined that the major species were ash-type eucalypts from south-eastern Australia (commonly referred to in the market as Tasmanian oak), jarrah from Western Australia, spotted gum, hoop pine, white cypress, blackbutt, brush box and Sydney blue gum from Queensland and New South Wales.

The environmental conditions data indicated that microclimates in shipping containers can fluctuate extensively during shipping. Conditions at the time of manufacturing were usually between 10 and 12% equilibrium moisture content, however conditions during shipping could range from 5 (very dry) to 20% (very humid). The packaging systems incorporated were reported to be efficient at protecting the wooden articles from damage during transit.

The research highlighted the potential risk for wood components to 'move' in response to periods of drier or more humid conditions than those at the time of manufacturing, and the importance of engineering a packaging system that can account for the environmental conditions experienced in shipping containers. Examples of potential dimensional changes in wooden components were calculated based on published unit shrinkage data for key species and the climatic data returned from the logging equipment. The information highlighted the importance of good design to account for possible timber movement during shipping. A timber movement calculator was developed to allow designers to input component species, dimensions, site of manufacture and destination, to see validate their product design. This calculator forms part of the free interactive website www.timberanswers.org.

AUTHOR PROFILE

Gary Hopewell is a Principal Scientist, Horticulture and Forestry Science, Queensland Department of Agriculture and Fisheries. He is based at the Salisbury Research Facility. Mr Hopewell was awarded a Master of Wood Science, University of Melbourne in 2005, based on this thesis. Professor Barbara Ozarska was the supervisor.

ANNUAL REPORT, ROYAL SOCIETY OF QUEENSLAND, 2014 – 2015

EDWARDS, G.

OVERVIEW

The Society has had an active year with several significant and well-attended events exploring contemporary issues in science and science policy. Membership is rising. Tax deductibility is in place for the Research Fund which has a very bright future. A couple of events on the horizon will, if progressed as intended, enhance the reputation of the Society and of scientific endeavour more generally. However, every silver lining has a cloud behind it. Our financial cash flow is less than desirable. The capacity of Council is limited by the absence of a designated Secretary. The time demands of organising events has constrained the time of Councillors available for policy formulation. This report summarises some of the happenings through the year. For more detailed accounts, please refer to the Newsletters of which nine have issued.

MEMBERSHIP

- Four current RSQ life members (Dr A Bailey, Dr J Jell, Dr J O'Hagan, Dr D Tugby).
- 111 current members, membership is increasing not decreasing as had occurred in previous years.

A survey of members via individual contact, although not yet quite complete, has yielded valuable information. For example, members obviously value the *Proceedings* highly and this must remain a centrepiece of the Society's contribution to science.

EVENTS

VISIT TO XYLARIA, SALISBURY RESEARCH CENTRE

Thanks to member Gary Hopewell for hosting a most interesting event attended by about 17 members and guests in July to Australia's only working public xylaria.

COMMUNITY INFRASTRUCTURE FORUM

The 24 June 2015 symposium on infrastructure co-sponsored with Engineers Australia Queensland and Institute for Future Environments, Queensland University of Technology was attended by about 70 people and generated warm feedback. Six excellent speakers stimulated lively discussion. A common theme emerging from the presentations was the need for much better strategic foresight in planning hard infrastructure projects. It is intended that the Society and Engineers Australia Queensland will collaborate on submitting a summary of the proceedings to government.

STEM EDUCATION BRAINSTORM

About 40 science educators attended a lively brainstorming event on 28 July 2015 co-sponsored with the Office of the Queensland Chief Scientist and hosted by the Science Faculty, Queensland University of Technology. Attendees presented summaries of their insights and experience in science education in print and by power points. One action arising from the plenary session was to develop an "information portal" for accessing authoritative materials for use by teachers. The Australian Academy of Technological Sciences and Engineering has offered to contribute personnel and an independent panel of experts is to be constituted to take the project further.

AWARDS

At the North Queensland Festival of Life Sciences celebration in November 2014, Member Professor Peter Leggat, Dean of the College of Public Health, Medical and Veterinary Sciences at James Cook University presented the inaugural Royal Society of Queensland awards to Martina Koeberl and Natasha Williams. Each student received a cash grant and two years' free membership of the Society. Congratulations to both. Council has agreed to offer the prize again this year and for three more years.

RESEARCH FUND

During the year the RSQ Research Fund, initiated by the Central Queensland Koala Volunteers, was granted charitable status and tax deductibility. I again pay tribute to Mark Ferguson of pro bono lawyers for his excellent support in steering our applications through the Australian Business Register and the Australian Tax Office. Three members have volunteered to serve on a Steering Committee that will generate publicity for the Fund and seek donations as precursor to dispersing grants.

WEBSITE

Digitisation of the *Proceedings* has been completed under the oversight of Council member Ben Lawson and proofreading is in progress. Queensland Museum and the State Library of Queensland assisted in making digital renditions of fragile paper copies. The result will be web-based full-text search capability of all issues including the *Transactions of the Philosophical Society of Queensland* (from 1859). This should greatly improve the exposure of the journal to an international audience. Scan Conversion Services, the company that undertook the digitisation, has generously offered to write a new website. Past President Paul Sattler granted to the Society the rights to web-publish his thoroughly fascinating memoirs, the first member to take advantage of our web publishing capacity beyond the *Proceedings*.

EDITORSHIP, *PROCEEDINGS OF THE ROYAL SOCIETY OF QUEENSLAND*

Dr Tanya Scharaschkin produced two volumes of the *Proceedings of the Royal Society of Queensland* – 118 and 119. We record our thanks for fine service. Dr Barry Pollock has generously volunteered to carry out the task of Editor, commencing with volume 120.

THANKS

I acknowledge again the loyal service of members of the outgoing Council - Ross Hynes, Ben Lawson, Cate Melzer, Barry Pollock, Tanya Scharaschkin and Craig Walton. I also thank those members and volunteers who have contributed to the well-being of the Society through the year. A special mention is made of the Education Task Force, the steering committee for the Community Infrastructure forum, usher Barry Jahnke, Librarian Kathy Buckley and associates at the Queensland Museum, Natasha Williams who has offered to organise North Queensland members and Kerensa McCallie who organised the Annual General Meeting. Thanks are due also to those who do no more than come to meetings, or just read the newsletters or website and thereby engage in this corner of the worldwide science community. Simply by paying your membership fees, you encourage and empower those who are in a position to take up more prominent roles.

CATE MELZER

The Annual General Meeting sees Cate leave the Council after 16 years of service. She has occupied various roles over this period. Important tasks have been setting up our pro bono legal relationship, coordinating the editing and printing of the *Proceedings*, foundational work on the Research Fund and coordinating Annual General Meetings. It is difficult in print to do justice to Cate's service to the Society. Any leader who serves for such a long period brings stability, continuity and judgement to an organisation. Cate has brought all of this – and more. In these days of short attention span, numerous competing demands upon discretionary time and crushing workloads upon serving public officers, it takes a special kind of person to devote 16 years to voluntary service to a small organisation. And it takes a special class of courage to uphold the standards of independent scientific inquiry and scientific tradition in the face of poor official recognition of these values, shrinking funding and denigration from the conservative press. That Cate has endeavoured throughout her tenure to uphold these standards is a tribute to her strength of character. That she has done so with goodwill, grace and cheerfulness is testament to her decency. Those who have known her and worked beside her salute her. And through the medium of the *Proceedings*, may readers be informed of her contribution to science for decades to come.

APPENDIX TO THE RSQ ANNUAL REPORT 2014 – 2015
AN INSIGHT FROM THE JULY 2015 EDUCATION BRAINSTORM

EDWARDS, G.

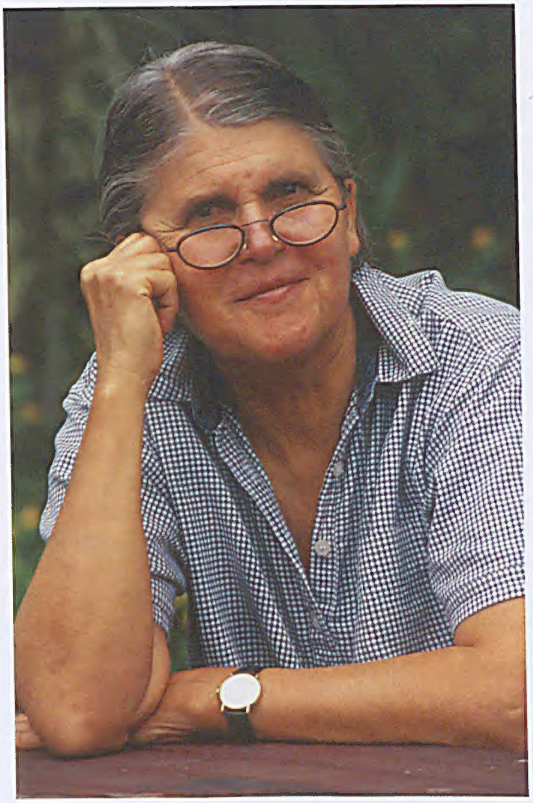
There was a fascinating exchange of views at the STEM Education Brainstorming event co-sponsored by The Royal Society of Queensland on 28 July 2015. The brainstorm was convened to consider why fewer secondary students in Queensland were choosing to study science and interest in taking up science as a career is said to be waning. It was a benchmark event in the Society's current investigation of the condition and trend of education in STEM (science, technology, engineering and mathematics). Not long into the proceedings, one participant challenged the notion that there was any shortfall in education in STEM. Many graduates were having difficulty finding work, particularly in engineering which is vulnerable to investment cycles such as in the mining or transport construction sectors.

This perspective echoed the views expressed by Mr Chris Warnock, President of Engineers Australia Queensland in opening the symposium on community infrastructure co-sponsored with the Society in June. Recent underinvestment in publicly funded construction projects means that large numbers of engineering graduates are without jobs. It takes some 11 years or more to educate and train an experienced engineer, so planning at the scale of decades is required to avoid this waste. Mr Warnock's observation about lead times certainly applies to science as well as engineering. The Society's Education Task Force in its hearings heard evidence that children make career-orientation decisions around their family dining tables during their middle primary years, six or seven years before they even enter tertiary study.

However, immediately and vigorously, several other participants challenged this perspective, claiming that the greatest benefit in educating students in science is not achieved by turning them into practising scientists, but in their ability to apply the principles of evidence-based scientific method in whatever career or role they enter. Some educators said that it was particularly important to ensure that budding leaders in business and government had a background in science. This is not just because of the rising profile of science-related issues such as climate change, energy depletion and the Great Barrier Reef in public affairs. It is because political discourse requires strong analytical capacity: respect for evidence, understanding of systems dynamics, tracing of cause and effect, prediction of logical consequences and openness to contrary perspectives. These are all features of orthodox scientific method.

At the Society's Annual General Meeting on 9 September 2015, Professor Emeritus Calvin Rose recounted the story of the establishment of the environmental studies course at Griffith University just on 40 years ago. Environmental studies relate to the impact on the public and common good of activity in the natural world. The discipline links up science, social sciences, economic policy and human health. This seems like a good grounding for any aspiring parliamentarian or policy officer!

OBITUARY OF JEANETTE COVACEVICH AM
1945 – 2015



Jeanette Covacevich was an active member of the Royal Society of Queensland. As a result of her outstanding contributions she was awarded Life Membership of the Society. Her other roles in the Society included:

- President 1995
- Secretary 1974 – 79
- Councillor 1984 – 87, 1994 – 98

She was co-convenor of Society conferences in 1974 (North Stradbroke Island); 1984 (Focus on Stradbroke); 1994 (Queensland: the State of Science); 1995 (The History of Natural History in Queensland); and 1996 (Exploring our Genes and Genetic Heritage).

Jeanette Covacevich well deserved her appointment as Life Member of the Society! Scholarship, humour, an understanding of practical conservation as well as taxonomy and her abiding interest in reptiles all shine through her presidential address in 1995, "Realities in the Biodiversity Holy Grail: Prospects for Reptiles of Queensland's Brigalow Biogeographic Region".

Jeanette Adelaide Covacevich was born in Innisfail on March 26, 1945, the elder of two children of Sir Thomas Covacevich and his wife, Gladys (née Bryant). Sir Thomas, a decorated RAF officer of World War II, was a Cairns solicitor and philanthropist. Jeanette grew up in Cairns, where she acquired a taste for outdoor adventure and a love of natural history. She attended Brisbane Girls Grammar School, where she excelled at swimming, then to the University of Queensland. She graduated with a BA majoring in geography and zoology in 1967, and later completed a Masters degree in environmental studies at Griffith University (1977).

In 1966, Jeanette joined the Queensland Museum in Brisbane as a cadet. She remained at the museum until her retirement in 2002, by which time she had risen through to be senior curator and co-head of Vertebrate Zoology. After retiring, she moved to Cooktown. She continued, in retirement, as an honorary research associate until her recent decline with an inoperable brain tumour. Her career was highly productive with her research interests focusing on the taxonomy and zoogeography of Australo-Papuan reptiles. She published more than 100 herpetological papers, which included the descriptions of 31 species, but she was particularly noted for her role in documenting the rediscovery of the Western Taipan, *Oxyuranus microlepidotus*, a dangerously venomous land snake that was lost to science for almost 100 years. To date, five species have been named in Jeanette Covacevich's honour by her colleagues – an earthworm, two spiders, a frog and a gecko.

Despite her focus on reptiles, her research interests were wide-ranging and extended to publications on the palm trees of north Queensland, Aboriginal trails and medicinal plants, history and medicine (especially following envenomation by snakebite). She was also an active contributor to the museum's exhibitions and publications programs, curating major exhibitions and working on a number of book projects. She was particularly proud of a best-selling

book, *Toxic Plants and Animals* (1987), which she co-edited with Peter Davie and John Pearn. Ms Covacevich's knowledge of venomous snakes led to her appointment from 1969 as consultant to the Queensland Poisons Information Centre. Her counsel to doctors and paramedics, freely given at all hours, contributed to the successful treatment of many snakebite victims. She was a member of the Queensland Naturalists' Club, president of the Australian Society of Herpetologists 1988-90 and a member of the Scientific Advisory Committee/ Queensland Nature Conservation Act, 1992. She also pursued an interest in island history and biogeography, visiting such places as Pitcairn Island, the Chatham Islands, St Helena (in the southern Atlantic), the Marquesas and Vanuatu. She also maintained her passion for fitness with strenuous swimming and bushwalking.

Jeanette was excellent company – cheerful, witty and knowledgeable – and never afraid to speak her mind. She once declared that the worst crime one could commit was to be boring; the next-worst was to be long-winded. Instead, she was in high demand as a public speaker. In the Queen's Birthday list in 1995, Ms Covacevich was awarded a Member in the General Division, Order of Australia (AM) for service to Science, particularly in the field of herpetology, and conservation. In 2003, she was awarded the Queensland Museum Medal, the Public Service Medal and the Queensland Natural History Award. In 2007, she received the Australian Natural History Medallion.

Jeanette Covacevich was a spirited and adventurous woman who made a lasting impression on all who knew her, often turning chance encounters into friendships. Professionally, she was widely respected in her dual roles of herpetologist and curator at the Queensland Museum. In her roles with the Royal Society, she strengthened the relationship that has existed since the Museum was born. Jeanette Covacevich is survived by her nieces, Emma and Lara. Her brother, John, predeceased her.

Edited from text by Patrick Couper, with Judith McKay, Bruce Campbell and John Pearn. Permission by Patrick Couper (Curator of Reptiles and Amphibians, Queensland Museum) and to reproduce the obituary in *The Sydney Morning Herald* of 1 October 2015 is acknowledged. Photo by Jeff Wright, copyright Queensland Museum.

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